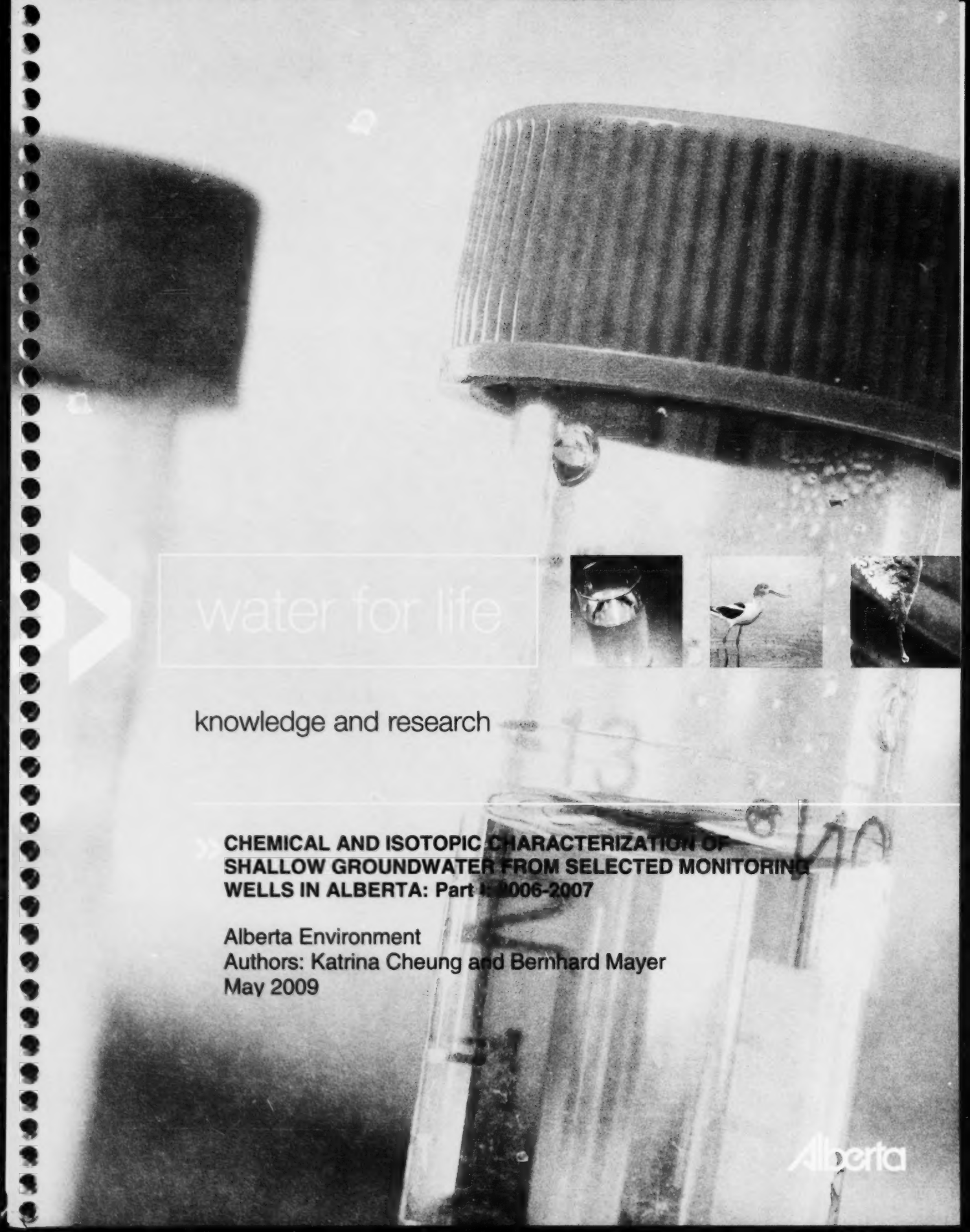

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CHEMICAL AND ISOTOPIC CHARACTERIZATION OF SHALLOW GROUNDWATER FROM SELECTED MONITORING WELLS IN ALBERTA: Part I: 2006-2007

Alberta Environment
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CHEMICAL AND ISOTOPIC CHARACTERIZATION OF SHALLOW GROUNDWATER FROM SELECTED MONITORING WELLS IN ALBERTA: Part I: 2006-2007

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March 31st, 2007

SUMMARY

Forty groundwater samples were obtained from shallow aquifers in Alberta for chemical and isotopic analyses in order to assess the current quality of Alberta's groundwater, and establish a baseline against which future impacts on groundwater can be evaluated. In addition, one groundwater well was selected for a quality control test and was repeatedly sampled for dissolved and free gas. The obtained water and gas samples were returned to the laboratory and submitted to various facilities for specialized chemical and isotopic analyses. Results from this study indicate that:

- Most groundwaters are of the Na-HCO_3 or Na-HCO_3-SO_4 type. Sodium (Na) concentrations were often above the aesthetic objective outlined by the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006). A few samples were characterized by very low sulphate concentrations indicating active bacterial sulphate reduction in the aquifer.
- Metal and trace element concentrations in most groundwater samples did not exceed any MAC or AO guidelines published by Health Canada (2006) with only few exceptions for Fe (3), F (11), Mn (8), Al (2), Ba (1), Hg (1), and Se (3).
- Concentrations of arsenic and chromium appear to be generally below drinking water guidelines.
- Concentrations of benzene and ethylbenzene were generally below the detection limit. Toluene was detected in 18 of the 40 samples, but only one sample exceeded the aesthetic objective outlined in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006).
- Analytical problems were encountered during determination of phenol and volatile organic acid (VOA) concentrations and hence a conclusive interpretation of the obtained results for these compounds is currently not possible.
- Polycyclic aromatic hydrocarbons (PAH's) in most groundwater samples were below the detection limit.
- Several groundwater samples showed traces of sulphide suggesting that bacterial sulphate reduction had occurred.
- Oxygen and hydrogen isotope ratios indicate that the groundwater is of meteoric origin but that significant evaporation had occurred during the recharge process.
- Sulphur and oxygen isotope ratios of dissolved sulphate indicate that oxidation of sulphide minerals such as pyrite is a major source of sulphate in groundwater.
- Only 3 groundwater samples had sufficient nitrate for isotope analysis. Nitrogen and oxygen isotope ratios of the nitrate suggested an agricultural or waste water source in two of the three cases.
- The carbon isotope ratios of methane in free gas varied between -84 and -60 ‰, suggesting a predominately biogenic source of the methane. Carbon isotope ratios of free ethane gas ranged from -66 to -44 ‰ in the groundwater samples, with the exception of the Warner 215 well with a $\delta^{13}C$ value of ethane of -36.1 ‰.

Preliminary methodological tests revealed excellent integrity of various gas storage containers over a period of 10 days, little variability of gas concentration and isotope ratios throughout a sampling day, and satisfying agreement between carbon isotope ratio measurements

on dissolved and free gas for several samples. Further improvements are, however, required before concentration and isotope measurements on dissolved gases can become a reliable routine tool in baseline water well testing, specifically for samples with low gas contents.

After this initial 4-month project, it appears that the chosen parameters are highly effective in assessing the status quo of groundwater quality in Alberta and that the sampling and analytical methodology was for the most part effective. Analytical problems that were encountered during phenol and volatile organic acid (VOA) analyses must be addressed in future monitoring efforts. It is currently unclear whether As and Cr speciation will yield reliable results due to the low total As and Cr concentrations in most aquifers. To improve the reliability of the obtained results and facilitate data processing, it is recommended that the analyses be carried out in fewer, but highly reliable contract laboratories.

Due to the increasing demand on water resources in Alberta it is highly recommended to expand this initial groundwater quality monitoring program to other Alberta Environment wells in the near future with as many water quality parameters as possible. Priority should be given to obtaining baseline water quality data from existing wells that have not been sampled recently. Thereafter, it is desirable to repeat this water quality monitoring program across the province in regular intervals. Re-sampling of individual wells is also recommended for sites where specific water quality problems have been detected.

There are still unresolved questions regarding the extent of temporal (e.g. seasonal) variability of concentrations and isotope ratios of naturally occurring dissolved and free gas in aquifers in Alberta. A systematic study assessing the seasonal variability of concentrations and isotope ratios of dissolved and free methane, higher alkanes, and CO_2 in selected groundwater wells completed in a variety of hydrogeological settings is recommended. It is important that such a study makes an attempt to distinguish between uncertainties introduced by the sampling techniques and natural variations in the concentrations and isotope ratios of dissolved and free gases. This will help to establish further background data against which future impacts, or the lack thereof, of the coalbed methane industry in the province can be tested.

The determination of the chemical and isotopic composition of groundwater from these 40 monitoring wells constitutes an important first step in assessing the status quo of Alberta's groundwater quality, providing a baseline against which future change in groundwater quality can be evaluated. Continued support for this initiative beyond the initial 4-month start-up phase will yield further insights into the fundamental geochemical processes determining groundwater quality in Alberta, natural and anthropogenic impacts on groundwater quality, and the sources and natural variability of dissolved and free gas in Alberta's groundwater dependent upon geological and hydrogeological settings. It is highly recommended that this program be expanded to include the remaining Alberta Environment monitoring wells in the near future.

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1.0 INTRODUCTION

Although production of coalbed methane (CBM) or natural gas from coal (NGC) is a relatively recent industry in Alberta, it is considered a vital new source of natural gas supply in Western Canada (Beaton et al., 2002; Beaton, 2002; Beaton et al., 2006). There are, however, significant environmental concerns, some of them related to potential negative impacts on shallow groundwater resources. These concerns stem often from issues that have been encountered in CBM-producing regions of the United States (e.g. Powder River Basin, San Juan Basin) including the disposal of saline produced waters (e.g. Clark et al., 2001; McBeth et al., 2003; Patz et al., 2004; Ganjegunte et al., 2005), leakage of produced gases into shallow aquifers (e.g. Beckstrom and Boyer, 1993) and drawdown of water levels in groundwater wells (e.g. Chafin et al., 1996). To address such environmental concerns in a scientifically sound manner, it is essential that the geochemical and isotopic compositions of shallow groundwater and produced waters and gases in CBM producing regions of Alberta be thoroughly known.

There have been only a few large-scale systematic studies investigating the chemical composition of shallow groundwater (Fitzgerald et al., 2001) and coal-bearing aquifers (Lemay, 2003; Lemay and Konhauser, 2006) in Alberta. Hence, the variability of the geochemical composition of shallow groundwater and the processes controlling this variability are not well understood. In addition, some of the shallow groundwater in Alberta is known to be naturally gas-containing. The source of this gas in shallow groundwater, however, is unclear.

To assess the potential impact of future CBM operations in Alberta on shallow aquifers, it is essential to understand the processes that determine the geochemical composition of water and gases in shallow aquifers under natural conditions, e.g. before industrial activity commences. Detailed geochemical analyses of shallow groundwater constitute a highly effective approach to develop a better understanding of the processes controlling the chemical composition of aquifers. In addition, stable isotope techniques provide a powerful tool for identifying the sources of water and its dissolved constituents (Kendall and McDonnell, 1998; Aggarwal et al., 2005) and the biogeochemical history of gases such as methane in groundwater systems (Aravena et al., 2003; Niemann et al., 2005; Rowe and Muehlenbachs, 1999a; Rowe and Muehlenbachs, 1999b; Whiticar, 1999).

The objectives of this project were (1) to identify reliable methods for analyzing the chemical and isotopic composition of free and dissolved gases in shallow groundwater, and (2) to thoroughly characterize the chemical and isotopic composition of shallow groundwater from selected wells in order to obtain a better knowledge of groundwater resources in the province. This information is crucial for future attempts to monitor potential impacts of produced fluids or gases from CBM operations on shallow aquifers. Hence, the project makes an essential and timely contribution to ensuring an environmentally sustainable extraction of coalbed methane, while protecting precious freshwater resources in shallow aquifers in Alberta. It is important to note that this project commenced in November 2006 and ended in March 2007, resulting in a project duration of only 4 months. It was possible to compile all the required analytical parameters, but the short project duration made it impossible to perform an in-depth analysis of the observed geochemical patterns in relation to well location, well depth, local or regional flow systems, recharge and discharge areas, etc.

2.0 STUDY AREA

Shallow groundwater was collected from monitoring wells accessing aquifers in the Central and Southern Plains of Alberta (Fig 1). The majority of the groundwater wells that were sampled are in contact with coal-bearing aquifers, such as the Scollard-Paskapoo and the Horseshoe Canyon aquifers. These two formations are being exploited for natural gas in coal (Fig 2).

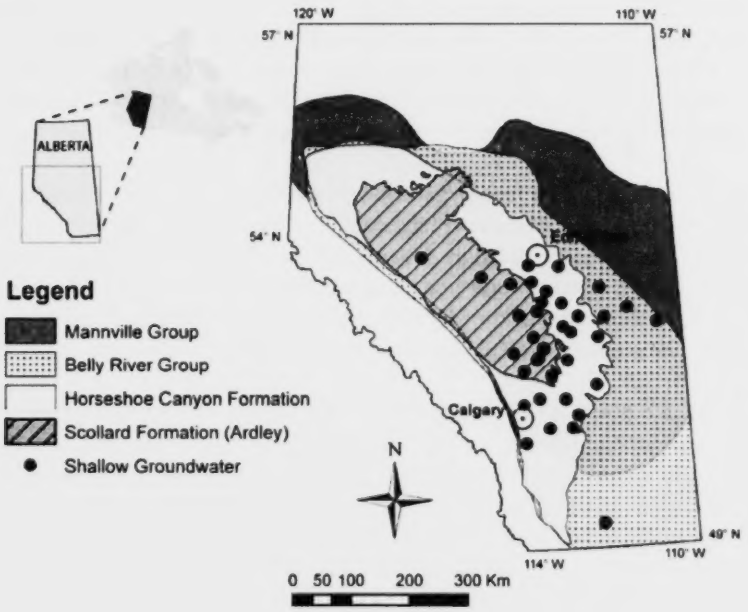

Figure 1: Map of Alberta showing the location of groundwater sampling sites with respect to the major coal bearing units (after Beaton, 2003). The Scollard formation contains the Ardley coal zone.

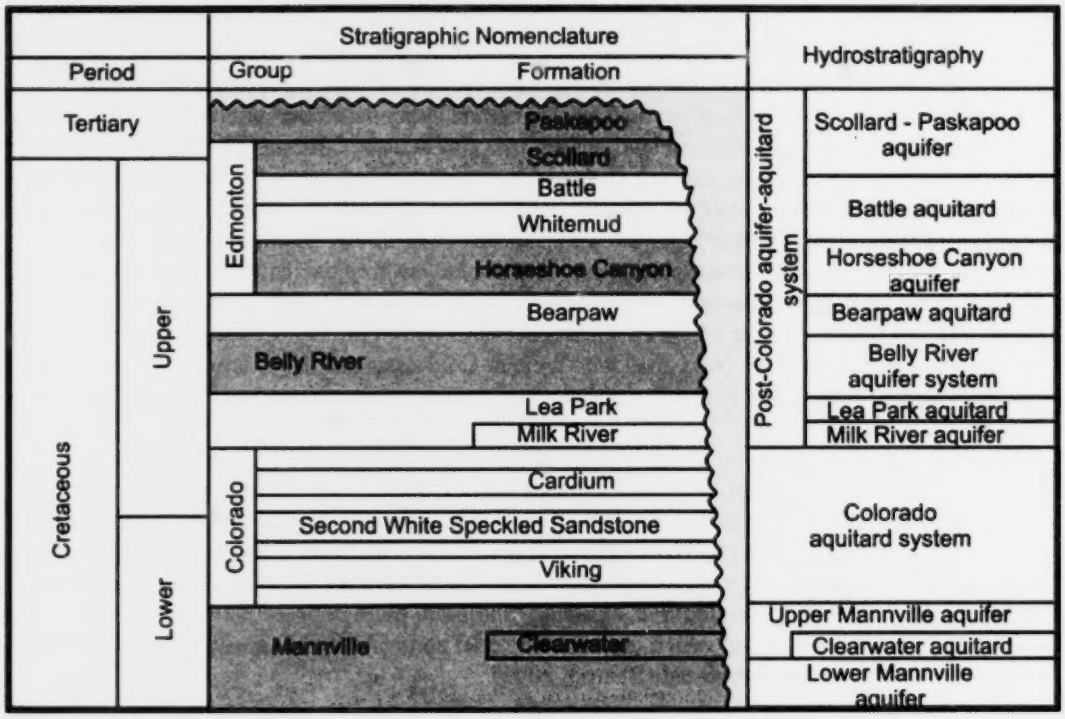

Figure 2: Basin scale stratigraphy and hydrostratigraphy of the Alberta Basin from the Cretaceous to the Tertiary (after Bachu, 1997)

2.1 Geology

The Alberta foreland basin consists of a passive margin succession of marine shales. Within this succession there are six clastic wedges that thin to the east; Fernie-Kooteney, Mannville, Dunvegan, Belly River, Edmonton and Paskapoo (Cant and Stockmal, 1989; Harrison et al., 2006). The Belly River, Edmonton and Paskapoo clastic wedges are of particular interest for this study, as the composition of these formations may affect the quality of groundwater in Alberta. These formations were deposited in mainly fluvial environments.

2.1.1 Scollard Formation

The Scollard Formation, which is part of the Edmonton group, consists of non-marine thick sandstone and siltstone interbedded with mudstone, shale and coal (Beaton, 2003; Harrison et al., 2006). The succession is characterized largely by a fluvial depositional setting. The Scollard Formation has been divided into two units, a lower and upper unit. These units are separated by the Cretaceous-Tertiary (K-T) boundary (Sweet and Braman, 1992). The Ardley coal zone is found in the upper unit of the Scollard Formation. The top of the Scollard Formation is overlain by Tertiary and Quaternary sediments. These sediments are poorly consolidated and are of glacial, fluvial, lacustrine, aeolian and organic origin (Dawson et al., 1994).

2.1.2 *Horseshoe Canyon Formation*

The Horseshoe Canyon Formation is part of the lower Edmonton Group in central Alberta (Figure 2). It consists of nonmarine sandstone, siltstone, shale, and mudstone. The mudstone contains coal, coaly shale and bentonite beds (Beaton, 2003). The sediments were deposited in a mildly brackish to freshwater environment. Based on studies by Rahmani (1983), the depositional environment of the Horseshoe Canyon Formation was a prograding deltaic complex that was fed by river(s) into the shallow and warm epicontinental Bearpaw Sea. The lower Horseshoe Canyon Formation consists of lagoonal, swamp, lacustrine, alluvial, and beach facies, whereas the upper Horseshoe Canyon Formation consists of clastic sediments of fluvial origin (Beaton, 2003). There are three main coal zones within the Horseshoe Canyon Formation: the Carbon-Thompson Coal Zone, the Daly-Weaver Coal Zone and the Drumheller Coal Zone. The thickness of coal seams in the Horseshoe Canyon Formation can exceed 4 meters (Beaton, 2003).

2.1.3 *Belly River Group*

The depositional environment of the Belly River Group is mainly nonmarine and consists of clay, silt and sand. The Belly River Group underlies the Bearpaw Formation and can be divided into two lithological units. The lower unit is the Foremost Formation, which contains two coal zones and was deposited in a shoreline to alluvial plain depositional setting. The upper unit is the Oldman Formation, which contains one coal zone and was deposited in a floodplain to lacustrine depositional environment (Beaton, 2003).

2.2 Hydrogeology

According to Bachu (1999), the flow systems in the Alberta Basin have developed due to: 1) erosional rebound flow and 2) local topography driven flow.

2.2.1 *Scollard-Paskapoo Aquifer*

The Scollard-Paskapoo aquifer is found at the top of the Upper Cretaceous-Tertiary succession (Figure 2). It is a shallow aquifer system whose flow is driven by topography. Recharge areas are at high elevations near the deformed belt and discharge areas are to the east-northeast (Harrison et al., 2006; Bachu, 1999; Bachu and Michael, 2003). The top of the Paskapoo aquifer is a target for fresh water supply and can yield from 6.5 m^3/day to 325 m^3/day (Harrison et al., 2006). Groundwater in the Scollard-Paskapoo aquifer is mainly fresh with TDS values of less than 2000 mg/L.

2.2.2 *Horseshoe Canyon Aquifer*

Flow in the Horseshoe Canyon aquifer is driven by topography north-eastward in the northern and southern areas (Bachu and Michael, 2003). Recharge occurs in the southwest and in the north-northwest and discharge occurs at lower elevations along river valleys. Within the centre area of the formation the flow is driven inward due to erosional rebound of the underlying Bearpaw shale (Bachu and Michael, 2003). Here, the aquifer is unable to recharge which suggests a low-permeability barrier between this area and the recharge areas in the southwest and north-northwest (Bachu and Michael, 2003). Overall, the Horseshoe Canyon aquifer is considered to be comparably dry relative to the Scollard-Paskapoo aquifer.

2.2.3 Brazeau-Belly River Aquifer

Based on studies by Michael et al. (2000), the flow in the Brazeau-Belly River aquifer is topography driven. The formation water within this aquifer is characterized by relatively high TDS values in topographic highs and relatively low TDS values in areas where the Brazeau outcrops. The water flows updip along the Lea Park aquitard and mixes with fresh meteoric waters. The Brazeau-Belly River aquifer and the Scollard-Paskapoo aquifer are in direct contact with one another northeast of the deformation front, due to the absence of the Battle Formation (Michael et al., 2000).

3.0 METHODS

A total of 40 groundwater wells were sampled by Alberta Environment field staff between November 2006 and March 2007. Of this total, 31 wells are part of Alberta Environment's Groundwater Observation Well Network (GOWN), 6 are municipal supply wells and 3 are private water wells used for stock watering and/or domestic purposes. The field site reference numbers used in this report were provided by Alberta Environment. The table in Appendix A links the field site numbers to the well type and GOWN reference number.

The water level in the well was measured to the top of the casing and then a video camera was lowered into the well to document well construction and condition. If no problems were found with the well's condition, the camera was removed and the total depth of the well was measured. Subsequently, a Grundfos pump was deployed 10 well diameters above the screened interval or open hole or as close as possible to this point and a Geotech 18" portable bladder pump with Teflon lined tubing was placed below the Grundfos pump in the screened interval. Above the Grundfos pump, an Insitu Level Troll 700 was installed to collect water level data at one second intervals during the pump test. The Grundfos pump was started and set to the required flow rate, using a gate valve that was deployed upstream of the gas separator so that back pressure could be applied to the pump without increasing pressure in the gas separator. The water from the pump was set to bypass the gas separator to allow the stored water to clear the well. Subsequently, a small amount of water was diverted from the discharge line upstream of the gas separator and run through a flow cell on a Hydrolab Datasonde 5 (DS5). The DS5 was calibrated at the beginning of the week and a post calibration check was preformed at the end of the week to check accuracy. The DS5 was used to collect water quality parameters, including: temperature, pH, conductivity, dissolved oxygen, turbidity and redox potential. Measurements were taken at one minute intervals and were used to determine when the well had been purged adequately prior to sampling. When sufficient purging had occurred the gas separator was filled with water and all air bubbles were removed. The gas sampler was then adjusted to produce a slight vacuum in the separator monitored by a compound gauge. Measurements were taken for pumping rate, water level in the well, and gas accumulation in the gas separator. These measurements were documented in the field notes along with pump deployment levels, size of pump and other field observations. After two hours of pumping, back pressure was applied to the gas sampler to allow the removal of free gas samples. The Grundfos pump was then shutoff to allow the well to recover.

Water samples for chemical and isotope analyses were collected using the bladder pump. The bladder pump was started and the water from the Teflon line was run through the DS5 to measure water quality parameters. The bladder pump ran until the water quality parameters were stable for 15 minutes and then the water samples were collected. The unfiltered samples were taken first and preserved as required. The dissolved gas samples were collected in a vial submersed in a bucket of water from the pump discharge. The tubing from the well discharge was inserted into the vial, and three volumes of water were allowed to flush through the vial. The vial was then sealed under water, before removing it from its submerged conditions to check for gas bubbles. An inline disposable 0.45 micron filter was then connected to the bladder pump hose and a couple of hundred milliliters of water were allowed to flow through the filter. After

flushing, filtered samples were obtained and preserved as required. Once all sample containers were filled the bladder pump was shutoff.

Quality control samples were taken to help verify the sampling quality. Two travel blanks (Cluny 5 and Cluny 6), and triplicate samples (Test Well 4 and Test well 5) were submitted for analysis to determine the accuracy and reproducibility of the field and laboratory methods used in this study. In addition, one groundwater well was repeatedly sampled for dissolved and free gas on March 13, 2007 over a period of 3 hours during which 13 samples were obtained. The obtained water and gas samples were preserved (where necessary), subdivided into different sample containers, and sent to various laboratories for determination of more than 95 chemical and isotopic parameters per groundwater sample. The analyzed parameters included major ions, metals, trace elements, potential water contaminants such as BTEX and PAH, isotopic ratios of water and dissolved constituents, and chemical and isotopic compositions of dissolved and free gases in an attempt to understand natural processes and potential anthropogenic influences impacting the quality of groundwater in Alberta.

3.1 Major Ion Chemistry

A filtered sample from each groundwater well was collected and acidified to pH < 2 with nitric acid for cation analysis. A filtered and un-acidified groundwater sample was collected from each well to be analyzed for major anions. The analytical work was conducted by Maxxam Analytics Inc. (Calgary). Methods used to determine anion concentrations in the groundwater samples included titration for bicarbonate, ion chromatography for nitrate, and automated colourimetry for chloride and sulphate. The detection limit for bicarbonate, chloride and sulphate is 0.5 mg/L, and for nitrate 0.003 mg/L. Maxxam also analyzed the samples for cation concentrations, but this lab changed their analytical technique during the project. In order to keep the data consistent, the cation concentrations derived from trace element analysis conducted by Becquerel Laboratories using ICP-MS were used for this report. The detection limits were as follows: for manganese 0.05 ppb, for iron 10 ppb, and for calcium, potassium, sodium, and magnesium 50 ppb.

3.2 Trace Elements

A filtered sample from each groundwater well was collected in a 125 mL Nalgene bottle and acidified to pH < 2 with nitric acid for elemental composition analysis. The analyses were conducted by Becquerel Laboratories (Ontario) using inductively coupled mass spectrometry (ICP-MS). The solution samples were diluted to below 0.1% of total dissolved solids before analysis. The detection limits ranged from 0.01 ppb for elements such as cesium, europium and rubidium to 1000 ppb for elements such as chlorine and sulphur.

3.3 Arsenic and Chromium Speciation

An unfiltered groundwater sample from each well was collected in a 250 mL plastic bottle and acidified with 5 mL of 20% nitric acid for analysis of the water's arsenic speciation (As^{3+} and As^{5+}). A filtered groundwater sample from each well was also collected in three 40 mL amber vials for total chromium, hexavalent chromium (Cr^{6+}) and trivalent chromium

(Cr^{3+}) determinations. The samples were sent to ALS Laboratories in Edmonton, Alberta, for analysis. The analysis for arsenic speciation was done by AAS – Hydride following the APHA 3114 C method. The detection limit for this analytical method is 0.05 µg/L. After all samples were analyzed for arsenic speciation, ALS Laboratories informed us that they had provided incorrect information regarding groundwater collection and preservation methods. Therefore, only total arsenic data are reported. Hexavalent chromium was analyzed using ion chromatography, and total chromium was analyzed using ICP-OES. The detection limit for this analytical method is 0.001 mg/L. Trivalent chromium was determined by calculating the difference between total chromium and hexavalent chromium. The detection limit for this method is 0.005 mg/L.

3.4 Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)

Unfiltered groundwater samples were collected in three 40 mL amber vials that were pre-loaded with 5 mL of 20% nitric acid. The samples were sent to ALS Laboratories in Calgary for analysis. Analytical methods followed the EPA 5030/805 and 8260 guidelines and analysis was conducted by GC-MS/FID. The detection limit for these analyses is 0.0005 mg/L.

3.5 Phenols

Groundwater from each well was collected in a 30 mL amber bottle for analysis of phenols. The samples were then acidified to pH < 2 using nitric acid. The bottles were sent to ALS Laboratories in Calgary. The samples were analyzed using automated colourimetry following the EPA 9066 procedure. The detection limit for phenols is 0.002 mg/L.

3.6 Volatile Organic Acids (as Acetic)

Unfiltered groundwater samples were collected in 500 mL amber bottles for analyses of volatile organic acids. The majority of the samples were sent to ALS Laboratories in Thunder Bay. The concentration of organic acids was determined by distillation/titration following the APHA 5560 C guidelines. The detection limit is 7 mg/L. Towards the end of the project ALS Laboratories changed their lab and samples were sent to Waterloo. This lab analyzed the samples using the same technique, but the detection limit was lowered significantly to 0.3 mg/L.

3.7 Polycyclic Aromatic Hydrocarbons (PAH)

Unfiltered groundwater samples were collected in 500 mL amber bottles for analysis of polyaromatic hydrocarbons. The samples were sent to Bodycote – Norwest Laboratories in Calgary, Alberta. The laboratory followed methods recommended by the US EPA and analysis was conducted by Gas Chromatography/Mass Spectrometry. The detection limit for PAHs is 0.01 µg/L, with the exception of fluoranthene and pyrene. The detection limit for these PAHs is 0.02 µg/L.

3.8 Sulphide Concentrations

Samples were collected in 30mL plastic Nalgene bottles for analysis of sulphide concentrations. The groundwater samples were mixed with a sulphide anti-oxidant buffer (SAOB) at a 1:1 ratio to preserve the water sample from further oxidation. The Applied Geochemistry Group at the University of Calgary using an ion specific electrode analyzed the groundwater samples. The sulphide concentration of the samples is recorded in mg/L.

3.9 Silica

Groundwater samples were filtered through a membrane filter with a 0.45 µm size mesh and collected in a 125 mL Nalgene bottle and acidified to pH < 2 with nitric acid. The concentration of silica was analyzed by Becquerel Laboratories (Ontario). The laboratory used an ICP-MS in order to determine the concentration of silica in the groundwater samples. The detection limit for this method was 1 ppb.

3.10 Stable Isotopes

3.10.1 Oxygen and Hydrogen

Samples for hydrogen and oxygen isotope ratio determinations were collected in 15 mL plastic vacu-tubes. The samples were analyzed in the Isotope Science Laboratory at the University of Calgary using dual inlet isotope ratio mass spectrometry. Oxygen and hydrogen isotope ratios are recorded using the usual delta (δ) notation (e.g. $\delta^{18}O_{water}$ and δD_{water}) in per mil (‰) deviation relative to V-SMOW. Accuracy and precision for δD_{water} is better than ±2.0 ‰ and for $\delta^{18}O_{water}$ is ±0.2 ‰.

3.10.2 Sulphur

Samples for sulphur isotope ratio determinations on dissolved sulphate were collected in 500 mL plastic Nalgene bottles. Sulphate was converted to barium sulphate ($BaSO_4$) and subsequently to SO_2. The sulphur isotope ratios were determined in the Isotope Science Laboratory at the University of Calgary, using continuous flow isotope ratio mass spectrometry. $\delta^{34}S_{sulphate}$ values are recorded in per mil (‰) relative to V-CDT. Accuracy and precision for $\delta^{34}S_{sulphate}$ is ±0.5 ‰.

3.10.3 Carbon

Samples for carbon isotope analyses on dissolved inorganic carbon (DIC) were collected in 15 mL plastic vacu-tubes that had been preloaded with ammonical strontium chloride. The resulting strontium carbonate samples were analyzed for carbon isotope ratios in the Isotope Science Laboratory at the University of Calgary as CO_2 gas released by phosphoric acid treatment followed by dual inlet isotope ratio mass spectrometry. $\delta^{13}C_{DIC}$ values are recorded in per mil (‰) relative to V-PDB. Accuracy and precision for $\delta^{13}C_{DIC}$ is ±0.2 ‰.

3.10.4 Nitrogen

The isotopic composition of nitrate was determined in the Isotope Science Laboratory at the University of Calgary on N_2O generated using the denitrifier technique. This technique requires a minimum nitrate concentration of 0.15 mg/L in the groundwater samples. Nitrogen isotope ratios of nitrate are expressed as $\delta^{15}N$ values in per mil (‰) relative to air, and oxygen

isotope ratios of nitrate are expressed in per mil (‰) relative to Vienna Standard Mean Ocean Water (V-SMOW). In most groundwater samples nitrate was not detectable, and hence determination of $\delta^{15}N$ and $\delta^{18}O$ values for nitrate was only possible for 3 samples.

3.11 Gas Composition

3.11.1 Dissolved Gas

Dissolved gas samples from each groundwater well were collected in three 40 mL clear glass vials with septa. The samples were analyzed for their composition by the Alberta Research Council Environmental Monitoring group in Vegreville. Groundwater samples were also collected in 125 mL glass bottles with crimp top lids and analyzed for their isotopic compositions at the Isotope Science Laboratory at the University of Calgary. The samples were analyzed using a gas chromatography combustion system coupled in continuous flow mode to an isotope ratio mass spectrometer (GC-C-IRMS). $\delta^{13}C$ values are recorded in per mil (‰) relative to V-PDB. Accuracy and precision for $\delta^{13}C_{CH4}$, $\delta^{13}C_{C2H6}$ and $\delta^{13}C_{CO2}$ is better than ±0.5 ‰.

3.11.2 Free Gas

Methane, ethane (where available) and CO_2 in free gas were collected using a flow through sampler and were transferred into 400 mL SS canisters and tedlar bags in the field. The Alberta Research Council Environmental Monitoring group in Vegreville determined gas compositional data. Gas compositional data are reported in ppmv in the gas phase, meaning that they are a measure of the relative abundance of each gas relative to the total volume of gas in the sample, rather than the amount of each gas per litre of water pumped. A duplicate sample in tedlar bags was submitted to the Isotope Science Laboratory at the University of Calgary for carbon isotope ratio determinations on methane, ethane and carbon dioxide. The samples were analyzed using a gas chromatography combustion system coupled in continuous flow mode to an isotope ratio mass spectrometer (GC-C-IRMS). $\delta^{13}C$ values are recorded in per mil (‰) relative to V-PDB. Accuracy and precision for $\delta^{13}C_{CH4}$, $\delta^{13}C_{C2H6}$ and $\delta^{13}C_{CO2}$ is better than ±0.5 ‰.

3.12 Geochemical Modeling

Standard geochemical models in the modeling program Aquachem v5.1 were used to calculate saturation indices (SI) for a number of different minerals. This reveals whether groundwater is under-saturated, in equilibrium, or over-saturated with respect to selected minerals commonly found in the aquifer matrix.

3.13 Quality Control Test

A quality control (QC) test was carried out on March 13, 2007, to determine the variability of the gas composition and isotope ratios along with the reproducibility of analytical procedures. The test was conducted at the Warner 215 well, since its groundwater contained free gas with high methane concentrations. According to the drilling reports the well was drilled though a coal seam. The well is located southeast of Lethbridge and is 98 m deep, which suggests that it most likely interacts with the Belly River group. Thirteen dissolved gas and free

gas samples were collected over a span of approximately three hours. One free gas and one dissolved gas sample were taken approximately every 15 minutes.

4.0 RESULTS AND DISCUSSION

4.1 Chemical and Isotopic Composition of Groundwater

Groundwater obtained from 40 wells in Alberta was analyzed for a wide variety of physical, chemical and isotopic parameters. The results are summarized and briefly described in section 4.1. For values below the detection limit, half of the detection limit was used for statistical calculations (Grunsky, 2000).

4.1.1 Field Parameters

Field parameters such as temperature, pH, electrical conductivity, alkalinity, redox potential, turbidity, dissolved oxygen, and total dissolved solids are summarized in Table 1. All groundwater samples were classified as fresh water (TDS < 4,000 mg/L) with the exception of groundwater from the Warner 214 well, which had a TDS value of 4,300 mg/L.

The pH of the samples ranged from 6.8 to 9.2 and temperatures ranged from 3.6 to 9.8 °C. The electrical conductivity of the groundwater samples varied between 606 to 7065 µS/cm. Dissolved oxygen contents ranged from 0.11 and 4.76 mg/L. The turbidity of the samples was low (0.2 to 90 NTU), with the exception of the Gull Lake 309 well, which had a turbidity of 140 NTU. The redox potential for the groundwater varied between -167 and 287 mV.

4.1.2 Major Ion Chemistry

Concentrations of major cations and anions are summarized in Table 2. For most samples, Na (ranging from 34 to 1820 mg/L) is the dominant cation, followed by Ca (ranging from 1.0 to 195.0 mg/L) and Mg (0.11 to 46.0 mg/L). All of the analyzed groundwater samples contained sodium (Na) concentrations above the aesthetic objective outlined by Health Canada (2006) with the exception of the Buffalo Lake OBS 4004C, ALTA Public Works #2, Stettler 60-4 OBS 137, Handhills 2 OBS 125, Galahad 292, Ferintosh OBS 147, and the Hardisty 1869 wells. Bicarbonate (HCO_3) was the dominant anion in the majority of the groundwater samples (below the detection limit to 2040 mg/L), followed by SO_4 and Cl (below the detection limit to 1010 mg/L and below the detection limit to 1530 mg/L, respectively). Groundwater from the Warner 214 and Metiskow 88-1 wells contained elevated concentrations of Cl (1530 mg/L and 741 mg/L, respectively) exceeding the aesthetic objective. It should be noted that both of these wells were completed at intervals greater than 100 m below surface, making them deeper than the average depth of 78 m for the wells in this study. Given their depth, there is a possibility that these wells are accessing a greater proportion of formation water than most other wells in this study. The concentration of nitrate in the groundwater samples ranged from below the detection limit to 3.36 mg/L with an average nitrate concentration of 0.130 mg/L. These low concentrations of nitrate are comparable to concentrations reported in other studies of coal-bearing aquifers in Alberta (Lemay, 2003; Lemay and Konhauser, 2006).

Water from all of the wells sampled in this study contained detectable dissolved fluoride with concentrations ranging from 0.09 mg/L in the Alta Public Works #2 well to 6.2 mg/L in the Gull Lake 309 well. Samples from eleven wells (Gull Lake 309, Water Well #1, Botanical Gardens 2327 OBS 160, Edson Well, Water Well #2, Warburg # 2187E OBS 316, Dickson Dam 308, Water Well #3, Pine Lake 398, Meadowglen 299, and Airdrie 456) showed fluoride concentrations that exceeded Health Canada's Maximum Acceptable Concentration (MAC) of 1.5 mg/L (Health Canada, 2006). Fluoride generally comes from natural sources, such as the dissolution of rock forming minerals, and low concentrations of the substance are harmless

(Health Canada, 2005). In sufficiently high doses over a long time period, however, it may cause health problems (Health Canada, 2005). According to the U.S. Environmental Protection Agency exposure to concentrations of fluoride greater than 2 mg/L may cause dental fluorosis in children and long-term exposure to fluoride concentrations greater than 4 mg/L can cause skeletal fluorosis in some individuals (EPA, 2007).

A Piper plot confirmed that most of the samples were of the Na-HCO_3 or Na-HCO_3-SO_4 type (Figure 3). Groundwater from Metiskow 88-1 was the only sample that had a Na-Cl water type and was also characterized by a TDS concentration above the upper quartile of 1230 mg/L (1590 mg/L). Only few samples plot in the Ca-HCO_3 category.

A Schoeller plot displaying major cation and anion concentrations (Figure 4) reveals that some groundwater samples were characterized by negligible sulphate concentrations. Under reducing conditions bacterial sulphate reduction (BSR) is a process that removes SO_4 and converts it to H_2S. Samples that contained low to undetectable sulphate concentrations were from Cluny, Gull Lake 309, Warner 214, Botanical Gardens 2327 OBS 160, Water Well #2, Warburg #2187E OBS 316, Water Well #3, Halkirk Town well, Handhills 1 OBS 124, Hardisty 1869, and Metiskow 88-1 wells. Methanogenesis becomes energetically favourable once BSR has occurred and only trace amounts of dissolved sulphate remain. It is interesting to note that the free gas from these wells contained also high concentrations of methane ranging from 16.7%v to 99.5%v (Table 11).

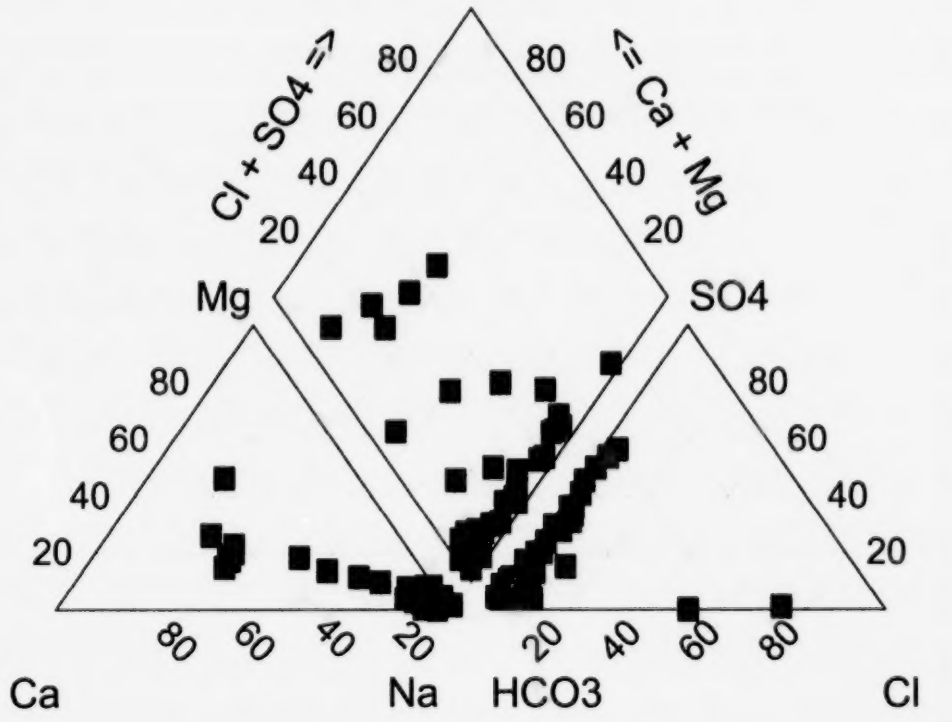

Figure 3: Piper plot showing the percent composition of major ions in groundwater (in meq/L) samples from 40 wells in Alberta.

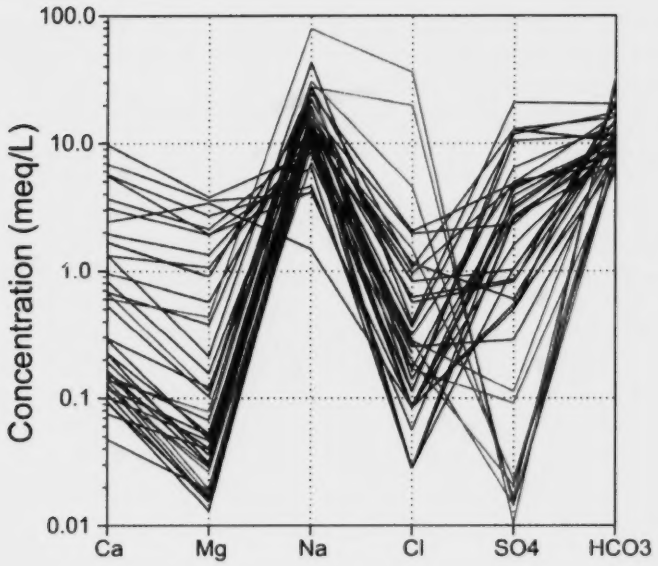

Figure 4: Schoeller Plot of the major ions in groundwater samples in 40 wells in Alberta. Groundwater samples in red contain low concentrations of sulphate compared to chloride (meq/L). These samples may be affected by bacterial sulphate reduction.

Table 1 Field parameters for groundwater samples in Alberta, Canada

Field Site	pH (Field)	Specific Conductance (µS/cm)	Temperature (°C)	Alkalinity Total CaCO3 (mg/L)
Cluny 85-1	8.6	873	7.5	492
Carseland	7.2	1082	6.6	340
Irricana	8.4	1385	7.8	454
Wheatland Rosebud	8.0	1496	9.8	777
Hussar Well	7.5	3558	6.6	1020
Gull Lake 309	9.0	1062	8.8	524
Warner 215	8.4	2245	8.6	885
Warner 214	7.7	7065	8.4	1720
Water Well #1	8.1	1166	7.6	609
Pine Lake 2688E	8.5	1245	5.2	577
Botanical Gardens 2327 OBS 160	8.5	1180	8.2	671
Ministik Lake 2322E OBS 438	7.7	1851	6.8	1070
Edson Well	9.0	869	5.4	489
Drayton Valley 368	7.9	1221	5.8	534
Water Well #2	8.4	1032	6.6	525
Ponoka 60-2 144	7.1	1266	5.0	521
Warburg #2187E OBS 316	9.2	746	7.8	430
Dickson Dam 308	9.2	1040	8.2	569
Elnora #6 128	7.7	2696	5.2	791
Water Well #3	8.5	1317	7.4	743
Donalda well	7.9	1772	6.7	707
Buffalo Lake OBS 4004C	7.2	1758	7.0	583
ALTA Public works #2	6.9	998	6.8	556
Halkirk Town well	7.5	2514	5.4	1480
Stettler 60-4 OBS 137	7.0	979	6.1	445
Handhills 1 OBS 124	8.5	896	6.6	526
Handhills 2 OBS 125	7.5	606	3.6	333
Olds OBS 227	7.5	2042	6.6	518
Olds OBS 126	7.6	1990	6.2	520
Okotoks 2378E217	7.7	921	7.4	483
Pine Lake 398	9.1	934	9.2	394
Meadowglen 299	8.4	1390	8.9	564
Three Hills RCA 144	8.2	2590	8.6	885
Wetaskiwin	8.3	1628	6.7	687
Galahad 292	7.6	1078	8.4	407
Airdrie 456	8.5	1218	8.0	629
Metiskow 88-2	8.9	1193	6.2	575
Ferintosh OBS 147	6.8	1131	8.6	533
Hardisty 1869	8.9	655	8.8	351
Metiskow 88-1	8.7	2969	6.7	385
Cluny 5	4.9	1	n.a.	n.d.
Cluny 6	6.2	8	n.a.	1.4
Test well 4	8.3	1940	n.a.	1080
Test well 5	8.3	1940	n.a.	1070

Table 1 (Cont'd...)

Statistical Parameter	pH (Field)	Specific Conductance (µS/cm)	Temperature (°C)	Alkalinity Total CaCO3 (mg/L)
Min	6.8	606	3.6	333.0
Median	8.2	1220	6.9	545.0
Max	9.2	7065	9.8	1720.0
Mean	8.1	1591	7.1	632.6
Lower Quartile	7.6	1024	6.5	487.5
Upper Quartile	8.5	1792	8.3	692.0
95th Percentile	9.1	2998	8.9	1090.5
Standard Deviation	0.7	1112	1.4	284.1
# Samples	40.0	40	40.0	40.0
95% Confidence	0.2	345	0.4	88.1

n.d. Not Detected
- Sample Not Available

Table 1 (Cont'd...)

Field Site	Total Dissolved Solids	Redox Potential	Turbitity	Oxygen Dissolved
	mg/L	mV	NTU	mg/L
Cluny 85-1	545	42	0.6	0.68
Carseland	711	44	25.0	0.30
Irricana	892	-15	6.2	0.41
Wheatland Rosebud	956	36	1.1	0.32
Hussar Well	2630	71	2.9	0.47
Gull Lake 309	627	98	140.0	0.29
Warner 215	1473	-83	0.5	0.65
Warner 214	4300	43	3.0	0.34
Water Well #1	719	210	0.2	2.18
Pine Lake 2688E	796	18	2.6	0.45
Botanical Gardens 2327 OBS 160	701	-42	0.5	0.57
Ministik Lake 2322E OBS 438	1160	-71	0.2	0.33
Edson Well	548	n.a.	0.2	0.54
Drayton Valley 368	818	62	3.5	0.33
Water Well #2	608	-44	0.6	0.35
Ponoka 60-2 144	820	85	2.8	0.63
Warburg #2187E OBS 316	485	-79	9.6	0.32
Dickson Dam 308	645	-9	18.0	0.72
Elnora #6 128	1840	25	5.1	0.45
Water Well #3	843	-167	0.6	0.13
Donalda well	1210	6	1.0	0.11
Buffalo Lake OBS 4004C	1290	87	70.0	0.32
ALTA Public works #2	659	196	13.0	0.16
Halkirk Town well	1830	19	0.3	0.11
Stettler 60-4 OBS 137	657	106	2.8	0.40
Handhills 1 OBS 124	570	84	3.9	0.73
Handhills 2 OBS 125	360	186	2.3	4.76
Olds OBS 227	1460	34	14.7	0.20
Olds OBS 126	1490	34	3.8	0.27
Okotoks 2378E217	630	163	11.0	1.45
Pine Lake 398	599	42	13.0	0.88
Meadowglen 299	843	287	2.0	4.31
Three Hills RCA 144	1750	53	1.4	0.39
Wetaskiwin	990	34	0.7	0.31
Galahad 292	720	47	51.0	0.33
Airdrie 456	761	-35	90.0	0.33
Metiskow 88-2	819	-67	7.6	0.35
Ferintosh OBS 147	726	121	19.0	0.48
Hardisty 1869	412	-73	0.7	0.38
Metiskow 88-1	1590	6	4.2	0.40
Cluny 5	n.d.	n.a.	n.d.	n.a.
Cluny 6	n.d.	n.a.	0.2	n.a.
Test well 4	1220	n.a.	7.2	n.a.
Test well 5	1210	n.a.	5.7	n.a

Table 1 (Cont'd...)

Statistical Parameter	Total Dissolved Solids	Redox Potential	Turbitity	Oxygen Dissolved
	mg/L	mV	NTU	mg/L
Min	360	-167	0.2	0.11
Median	807	36	3.0	0.39
Max	4300	287	140.0	4.76
Mean	1037	40	13.4	0.68
Lower Quartile	641	-12	0.7	0.32
Upper Quartile	1230	85	11.5	0.58
95th Percentile	1880	197	71.0	2.29
Standard Deviation	714	90	27.9	0.97
# Samples	40	39	40.0	40.00
95% Confidence	221	28	8.6	0.30

n.d. Not Detected
- Sample Not Available

Table 2 Major cation and anion concentrations of groundwater samples in Alberta, Canada

Field Site	Ca^{2+}	Fe^{2+}	K^{+}	Mg^{2+}	Mn^{2+}	Na^{+}
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Cluny 85-1	2.2	0.041	0.56	0.19	0.004	
Carseland	3.9		2.00	16.00		
Irricana	4.5	0.037	0.87	0.64	0.010	
Wheatland Rosebud	3.8	0.063	0.88	0.44	0.010	
Hussar Well	26.0		2.00	2.60	0.022	
Gull Lake 309	3.3		0.77	0.24	0.002	
Warner 215	3.1	n.d.	1.40	0.81	0.001	
Warner 214	12.0	0.26	3.80	5.30	0.003	
Water Well #1	2.1	n.d.	0.82	0.57	0.002	
Pine Lake 2688E	2.9	0.017	0.72	0.49	0.005	
Botanical Gardens 2327 OBS 160	2.6	0.047	0.68	0.19	0.004	
Ministik Lake 2322E OBS 438	5.8	0.043	2.10	0.58	0.004	
Edson Well	1.0	n.d.	0.48	0.23	0.001	
Drayton Valley 368	19.0	0.056	1.30	6.90	0.031	
Water Well #2	1.9	0.022	0.60	0.16	0.003	
Ponoka 60-2 144	74.0		2.90	26.00		
Warburg #2187E OBS 316	1.2	0.046	0.56	0.11	0.005	
Dickson Dam 308	1.5	0.013	1.10	0.48	0.002	
Elnora #6 128	14.0	0.24	2.20	4.60	0.022	
Water Well #3	2.8	0.016	0.67	0.21	0.035	
Donalda well	17.0	n.d.	1.80	1.90	0.011	
Buffalo Lake OBS 4004C	195.0		2.90	46.00		192
ALTA Public works #2	62.0		3.20	23.00		148
Halkirk Town well	13.0	0.089	6.00	1.40	0.007	
Stettler 60-4 OBS 137	111.0		4.70	23.00		95
Handhills 1 OBS 124	2.4	0.21	0.84	0.32	0.017	
Handhills 2 OBS 125	49.0	n.d.	4.50	41.00	0.010	34
Olds OBS 227	34.0		3.70	11.00		
Olds OBS 126	33.6	0.28	3.60	11.00	0.048	
Okotoks 2378E217	27.0	0.031	2.50	13.00	0.018	
Pine Lake 398	1.9	0.011	0.58	0.20	0.005	
Meadowglen 299	11.0	0.094	1.30	1.20	0.020	
Three Hills RCA 144	3.3	n.d.	0.79	0.36	0.004	
Wetaskiwin	4.5	0.041	0.77	0.38	0.010	
Galahad 292	113.0		4.50	33.00		106
Airdrie 456	5.9		1.30	1.50	0.017	
Metiskow 88-2	2.4	0.029	2.20	0.63	0.002	
Ferintosh OBS 147	138.0		2.50	43.00		93
Hardisty 1869	2.4	0.024	0.96	0.35	0.002	165
Metiskow 88-1	2.8	0.05	2.40	1.00	0.006	
Cluny 5	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-
Test well 5						

Table 2 Major cation and anion concentrations of groundwater samples in Alberta, Canada

Field Site	Ca^{2+}	Fe^{2+}	K^{+}	Mg^{2+}	Mn^{2+}	Na^{+}
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Cluny 85-1	2.2	0.041	0.56	0.19	0.004	231
Carseland	3.9	0.42	2.00	16.00	0.260	217
Irricana	4.5	0.037	0.87	0.64	0.010	359
Wheatland Rosebud	3.8	0.063	0.88	0.44	0.010	396
Hussar Well	26.0	0.32	2.00	2.60	0.022	989
Gull Lake 309	3.3	0.35	0.77	0.24	0.002	292
Warner 215	3.1	n.d.	1.40	0.81	0.001	573
Warner 214	12.0	0.26	3.80	5.30	0.003	1820
Water Well #1	2.1	n.d.	0.82	0.57	0.002	317
Pine Lake 2688E	2.9	0.017	0.72	0.49	0.005	340
Botanical Gardens 2327 OBS 160	2.6	0.047	0.68	0.19	0.004	339
Ministik Lake 2322E OBS 438	5.8	0.043	2.10	0.58	0.004	515
Edson Well	1.0	n.d.	0.48	0.23	0.001	252
Drayton Valley 368	19.0	0.056	1.30	6.90	0.031	319
Water Well #2	1.9	0.022	0.60	0.16	0.003	285
Ponoka 60-2 144	74.0	0.36	2.90	26.00	0.059	233
Warburg #2187E OBS 316	1.2	0.046	0.56	0.11	0.005	207
Dickson Dam 308	1.5	0.013	1.10	0.48	0.002	264
Elnora #6 128	14.0	0.24	2.20	4.60	0.022	630
Water Well #3	2.8	0.016	0.67	0.21	0.035	348
Donalda well	17.0	n.d.	1.80	1.90	0.011	432
Buffalo Lake OBS 40040	195.0	5.2	2.90	46.00	0.410	192
ALTA Public works #2	62.0	0.75	3.20	23.00	0.160	148
Halkirk Town well	13.0	0.089	6.00	1.40	0.007	706
Stettler 60-4 OBS 137	111.0	1.6	4.70	23.00	0.260	95
Handhills 1 OBS 124	2.4	0.21	0.84	0.32	0.017	240
Handhills 2 OBS 125	49.0	n.d.	4.50	41.00	0.010	34
Olds OBS 227	34.0	0.57	3.70	11.00	0.051	452
Olds OBS 126	33.6	0.28	3.60	11.00	0.048	444
Okotoks 2378E 217	27.0	0.031	2.50	13.00	0.018	214
Pine Lake 398	1.9	0.011	0.58	0.20	0.005	238
Meadowglen 299	11.0	0.094	1.30	1.20	0.020	648
Three Hills RCA 144	3.3	n.d.	0.79	0.36	0.004	335
Wetaskiwin	4.5	0.041	0.77	0.38	0.010	399
Galahad 292	113.0	3.5	4.50	33.00	0.082	106
Airdrie 456	5.9	1.04	1.30	1.50	0.017	319
Metiskow 88-2	2.4	0.029	2.20	0.63	0.002	309
Ferintosh OBS 147	138.0	2.1	2.50	43.00	0.210	93
Hardisty 1869	2.4	0.024	0.96	0.35	0.002	165
Metiskow 88-1	2.8	0.05	2.40	1.00	0.006	635
Cluny 5						
Cluny 6						
Test well 4						
Test well 5						

Table 2 (Cont'd...)

Statistical Parameter	Ca^{2+}	Fe^{2+}	K^{+}	Mg^{2+}	Mn^{2+}	Na^{+}
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Min	1.0	0.01	0.48	0.11	0.00	34.0
Median	4.5	0.05	1.4	0.9	0.01	318.0
Max	195.0	5.20	6.0	46.00	0.41	1820.0
Mean	25.4	0.45	1.9	8.0	0.05	378.3
Lower Quartile	2.6	0.02	0.8	0.4	0.00	227.5
Upper Quartile	26.3	0.33	2.6	11.0	0.03	435.0
95th Percentile	114.3	2.17	4.5	41.1	0.26	720.1
Standard Deviation	43.3	1.02	1.4	13.1	0.09	301.7
# Samples	40.0	40.00	40.0	40.0	40.00	40.0
95% Confidence	13.4	0.32	0.4	4.1	0.03	93.5

n.d. Not Detected
\- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 2 (Cont'd...)

Field Site	HCO_3^-	NO_3^-	SO_4^{2-}	Cl	F^-
	mg/L	mg/L	mg/L	mg/L	mg/L
Cluny 85-1	554	n.d.	n.d.	9.3	1.28
Carseland	415	n.d.	239.0	14.5	0.52
Irricana	513	n.d.	223.0	44.1	1.43
Wheatland Rosebud	930	n.d.	49.4	36.0	0.9
Hussar Well	1250	n.d.	1010.0	16.2	0.24
Gull Lake 309	572	0.066	1.1	47.3	6.16
Warner 215	1010	0.147	231.3	95.1	0.94
Warner 214	2040	0.013	0.5	1530.0	0.35
Water Well #1	684	0.258	40.7	19.0	4.1
Pine Lake 2688E	663	n.d.	147.0	1.0	0.98
Botanical Gardens 2327 OBS 160	733	0.013	n.d.	10.6	2.07
Ministik Lake 2322E OBS 438	1250	0.015	39.1	25.8	0.51
Edson Well	499	0.007	13.7	9.8	2.24
Drayton Valley 368	633	n.d.	187.0	1.4	0.2
Water Well #2	598	n.d.	n.d.	37.3	2.38
Ponoka 60-2 144	636	n.d.	210.0	3.4	0.23
Warburg #2187E OBS 316	462	0.011	1.0	10.2	2.51
Dickson Dam 308	534	n.d.	24.0	3.7	2.15
Elnora #6 128	965	n.d.	618.0	37.4	0.73
Water Well #3	848	n.d.	5.4	11.9	1.66
Donalda well	847	0.006	310.0	4.0	0.44
Buffalo Lake OBS 4004C	711	n.d.	499.0	4.6	0.21
ALTA Public works #2	679	n.d.	50.6	1.6	0.09
Halkirk Town well	1750	n.d.	0.8	170.0	0.24
Stettler 60-4 OBS 137	543	n.d.	129.0	3.9	0.11
Handhills 1 OBS 124	605	n.d.	0.7	10.6	0.98
Handhills 2 OBS 125	407	0.863	26.2	3.6	0.29
Olds OBS 227	631	0.010	609.0	4.2	0.54
Olds OBS 126	634	0.032	618.0	8.4	0.52
Okotoks 2378E217	589	3.360	76.5	3.9	0.75
Pine Lake 398	424	0.015	125.3	2.5	3.95
Meadowglen 299	661	0.337	161.0	17.5	1.86
Three Hills RCA 144	1050	0.004	568.0	7.7	0.99
Wetaskiwin	798	0.007	111.0	83.6	0.48
Galahad 292	497	0.010	224.0	2.2	0.16
Airdrie 456	722	n.d.	28.7	48.6	3.73
Metiskow 88-2	617	n.d.	121.0	2.6	0.45
Ferintosh OBS 147	650	n.d.	150.0	1.4	0.11
Hardisty 1869	371	0.007	4.4	11.3	0.84
Metiskow 88-1	433	n.d.	0.7	741.0	1.41
Cluny 5	n.d.	n.d.	1.0	n.d.	n.d.
Cluny 6	2	n.d.	2.0	n.d.	n.d.
Test well 4	1300	0.007	24.4	25.3	0.51
Test well 5	1300	0.010	24.6	25.5	0.51

Table 2 (Cont'd...)

Statistical Parameter	HCO_3^-	NO_3^-	SO_4^{2-}	CT	F^-
	mg/L	mg/L	mg/L	mg/L	mg/L
Min	371.0	0.002	0.3	1.0	0.09
Median	635.0	0.002	93.8	10.4	0.80
Max	2040.0	3.360	1010.0	1530.0	6.16
Mean	735.2	0.130	171.4	77.4	1.24
Lower Quartile	540.8	0.002	5.2	3.9	0.34
Upper Quartile	810.3	0.013	223.3	36.3	1.71
95th Percentile	1275.0	0.363	618.0	198.5	3.96
Standard Deviation	343.4	0.545	231.1	263.5	1.33
# Samples	40.0	40.000	40.0	40.0	40.00
95% Confidence	106.4	0.169	71.6	81.7	0.41

n.d. Not Detected
\- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

4.1.3 *Trace Elements*

The concentrations of seventy elements occurring in groundwater were determined and compared to the maximum allowable concentrations (MAC) and aesthetic objective (AO) guidelines established by Health Canada (2006). Results are summarized in Table 3. Groundwater from the Carseland, Ponoka 60-2 144, Buffalo Lake OBS 4004C, ALTA Public Works #2, Stettler 60-4 OBS 137, Olds OBS 227, Galahad 292, and Ferintosh OBS 147 wells contained manganese concentrations exceeding the AO of 50 µg/L. Elevated concentrations of manganese were associated with elevated concentrations of iron (> 359 µg/L). The concentrations of iron and manganese reported in this study are similar, or slightly higher compared to others reported for coal-bearing aquifers in Alberta (Lemay, 2003; Lemay and Konhauser, 2006). Groundwater from the Hussar, Gull Lake 309, and Airdrie 456 wells contained elevated concentrations of iron, but not manganese. Groundwater from the Airdrie 456 well contained 322 µg/L of Al, which exceeds the AO outlined by Health Canada (2006). Groundwater from the Warner 214 well contained elevated concentrations of Ba (1186 µg/L), Hg (8.2 µg/L), and Se (70.1 µg/L) exceeding the MAC. Groundwater from the Metiskow 88-1 well and Halkirk Town well also contained elevated Se concentrations (57.4 µg/L and 12.4 µg/L, respectively). Aside from the exceptions listed above, none of the samples analyzed for this study exceeded the MAC or AO guidelines published by Health Canada (2006).

4.1.4 *Arsenic and Chromium Speciation*

Total concentrations of arsenic in the groundwater samples range from below the detection limit to 7.5 µg/L, which is less than the MAC of 10 µg/L (Health Canada, 2006). Only groundwater from the Gull Lake 309 well contained chromium concentrations above the MAC at 69 µg/L. Groundwater samples were also analyzed for their arsenic and chromium speciation. The oxidation state and speciation of elements is an important factor in determining their bioavailability and ecotoxicity (As^{3+} vs. As^{5+}; Cr^{6+} vs. Cr^{3+}). For example, Cr^{6+} is more toxic and mobile than Cr^{3+}. Trivalent chromium is highly insoluble and forms oxides, hydroxides, and phosphates. Conversely, hexavalent chromium is very soluble, has a long residence time in surface and groundwater, and is a carcinogen (Pawlisz et al., 1997). Unfortunately, due to errors during sample processing, arsenic speciation results are not available. Results for the speciation of chromium are listed in Table 4. The chromium speciation results show that concentrations of hexavalent and trivalent chromium were below the detection limit in the majority of the groundwater samples, with the exception of groundwater from the Water Well #2, Stettler 60-4 OBS 137 and the Wetaskiwin wells. The concentration of trivalent chromium in the Water Well #2 and Stettler 60-4 OBS 137 wells (0.002 µg/L, and 0.001 µg/L, respectively) and that of hexavalent chromium in the Wetaskiwin well (0.006 µg/L) were below the drinking water guidelines outlined by Health Canada (2006). In some cases, these results are in disagreement with total chromium concentration data reported by Becquerel laboratories summarized in Table 3 that indicated concentrations of total chromium for Gull Lake 309 of 69 µg/L and 5.4 µg/L for Warner 214. Since the detection limit for hexavalent chromium is 1 µg/L and the detection limit for trivalent chromium is 5 µg/L, chromium speciation should have yielded higher concentrations at least for groundwater from Gull Lake 309 provided that the Becquerel analyses for total chromium were accurate. It is suggested to re-test these wells for chromium and arsenic speciation as well as total chromium concentrations before further conclusions are drawn and the value of As and Cr speciation can be evaluated.

Table 3 Elemental composition of groundwater samples in Alberta, Canada

Field Site	Ag	Al	As	Au	B	Ba	Be	Bi	Br
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	5	n.d.	n.d.	374	29	n.d.	n.d.	64
Carseland	n.d.	1	n.d.	n.d.	180	15	n.d.	n.d.	187
Irricana	n.d.	4	n.d.	n.d.	163	10	n.d.	n.d.	279
Wheatland Rosebud	n.d.	8	2.2	n.d.	286	49	n.d.	n.d.	160
Hussar Well	n.d.	79	n.d.	n.d.	410	5	n.d.	n.d.	57
Gull Lake 309	n.d.	7	0.8	n.d.	614	23	n.d.	n.d.	264
Warner 215	n.d.	2	n.d.	n.d.	544	143	n.d.	n.d.	1717
Warner 214	n.d.	13	7.5	n.d.	1403	1186	n.d.	n.d.	29375
Water Well #1	n.d.	5	n.d.	n.d.	204	87	n.d.	n.d.	157
Pine Lake 2688E	n.d.	1	n.d.	n.d.	312	12	n.d.	n.d.	27
Botanical Gardens 2327 OBS 160	n.d.	5	n.d.	n.d.	260	73	n.d.	n.d.	220
Ministik Lake 2322E OBS 438	n.d.	1	0.7	n.d.	126	149	n.d.	n.d.	230
Edson Well	n.d.	4	n.d.	n.d.	255	29	n.d.	n.d.	44
Drayton Valley 368	n.d.	1	0.5	n.d.	200	19	0.06	n.d.	29
Water Well #2	n.d.	1	n.d.	n.d.	282	54	n.d.	n.d.	230
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.	244	24	n.d.	n.d.	33
Warburg #2187E OBS 316	n.d.	12	n.d.	n.d.	362	17	0	n.d.	66
Dickson Dam 308	n.d.	4	0.9	0.10	158	190	n.d.	n.d.	42
Elnora #6 128	n.d.	1	n.d.	n.d.	281	7	n.d.	n.d.	87
Water Well #3	n.d.	1	n.d.	n.d.	282	70	n.d.	n.d.	159
Donalda well	n.d.	1	n.d.	n.d.	245	11	0.18	n.d.	69
Buffalo Lake OBS 4004C	n.d.	n.d.	2.9	n.d.	75	25	n.d.	n.d.	128
ALTA Public works #2	n.d.	n.d.	n.d.	n.d.	412	53	n.d.	n.d.	31
Halkirk Town well	n.d.	n.d.	1.7	n.d.	288	229	n.d.	n.d.	1485
Stettler 60-4 OBS 137	n.d.	n.d.	3.5	n.d.	114	47	0.22	n.d.	58
Handhills 1 OBS 124	n.d.	2	n.d.	n.d.	216	30	0.21	n.d.	112
Handhills 2 OBS 125	n.d.	2	n.d.	n.d.	29	108	0.1	n.d.	116
Olds OBS 227	n.d.	1	3.3	n.d.	213	8	0.1	n.d.	92
Olds OBS 126	n.d.	1	3.6	n.d.	206	6	n.d.	n.d.	90
Okotoks 2378E 217	n.d.	n.d.	n.d.	n.d.	123	29	0.1	n.d.	61
Pine Lake 398	n.d.	5	n.d.	n.d.	362	17	0.1	n.d.	37
Meadowglen 299	n.d.	n.d.	n.d.	n.d.	336	7	n.d.	n.d.	52
Three Hills RCA 144	n.d.	1	1.4	n.d.	203	32	n.d.	n.d.	26
Wetaskiwin	n.d.	n.d.	0.5	n.d.	327	91	0.1	n.d.	514
Galahad 292	n.d.	n.d.	4.8	n.d.	205	32	0.2	n.d.	41
Airdrie 456	n.d.	322	n.d.	n.d.	161	197	0.2	n.d.	156
Metiskow 88-2	n.d.	6	n.d.	n.d.	862	16	n.d.	n.d.	27
Ferintosh OBS 147	n.d.	n.d.	n.d.	n.d.	24	20	n.d.	n.d.	63
Hardisty 1869	n.d.	2	n.d.	n.d.	1050	33	n.d.	n.d.	70
Metiskow 88-1	n.d.	2	3.9	0.14	1815	72	n.d.	n.d.	7316
Cluny 5									
Cluny 6									
Test well 4									
Test well 5									

Table 3 Elemental composition of groundwater samples in Alberta, Canada

Field Site	Ag	Al	As	Au	B	Ba	Be	Bi	Br
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	5	n.d.	n.d.	374	29	n.d.	n.d.	64
Carseland	n.d.	1	n.d.	n.d.	180	15	n.d.	n.d.	187
Irricana	n.d.	4	n.d.	n.d.	163	10	n.d.	n.d.	279
Wheatland Rosebud	n.d.	8	2.2	n.d.	286	49	n.d.	n.d.	160
Hussar Well	n.d.	79	n.d.	n.d.	410	5	n.d.	n.d.	57
Gull Lake 309	n.d.	7	0.8	n.d.	614	23	n.d.	n.d.	264
Warner 215	n.d.	2	n.d.	n.d.	544	143	n.d.	n.d.	1717
Warner 214	n.d.	13	7.5	n.d.	1403	1186	n.d.	n.d.	29375
Water Well #1	n.d.	5	n.d.	n.d.	204	87	n.d.	n.d.	157
Pine Lake 2688E	n.d.	1	n.d.	n.d.	312	12	n.d.	n.d.	27
Botanical Gardens 2327 OBS 160	n.d.	5	n.d.	n.d.	260	73	n.d.	n.d.	220
Ministik Lake 2322E OBS 438	n.d.	1	0.7	n.d.	126	149	n.d.	n.d.	230
Edson Well	n.d.	4	n.d.	n.d.	255	29	n.d.	n.d.	44
Drayton Valley 368	n.d.	1	0.5	n.d.	200	19	0.06	n.d.	29
Water Well #2	n.d.	1	n.d.	n.d.	282	54	n.d.	n.d.	230
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.	244	24	n.d.	n.d.	33
Warburg #2187E OBS 316	n.d.	12	n.d.	n.d.	362	17	0	n.d.	66
Dickson Dam 308	n.d.	4	0.9	0.10	158	190	n.d.	n.d.	42
Elnora #6 128	n.d.	1	n.d.	n.d.	281	7	n.d.	n.d.	87
Water Well #3	n.d.	1	n.d.	n.d.	282	70	n.d.	n.d.	159
Donalda well	n.d.	1	n.d.	n.d.	245	11	0.18	n.d.	69
Buffalo Lake OBS 4004C	n.d.	n.d.	2.9	n.d.	75	25	n.d.	n.d.	128
ALTA Public works #2	n.d.	n.d.	n.d.	n.d.	412	53	n.d.	n.d.	31
Halkirk Town well	n.d.	n.d.	1.7	n.d.	288	229	n.d.	n.d.	1485
Stettler 60-4 OBS 137	n.d.	n.d.	3.5	n.d.	114	47	0.22	n.d.	58
Handhills 1 OBS 124	n.d.	2	n.d.	n.d.	216	30	0.21	n.d.	112
Handhills 2 OBS 125	n.d.	2	n.d.	n.d.	29	108	0.1	n.d.	116
Olds OBS 227	n.d.	1	3.3	n.d.	213	8	0.1	n.d.	92
Olds OBS 126	n.d.	1	3.6	n.d.	206	6	n.d.	n.d.	90
Okotoks 2378E217	n.d.	n.d.	n.d.	n.d.	123	29	0.1	n.d.	61
Pine Lake 398	n.d.	5	n.d.	n.d.	362	17	0.1	n.d.	37
Meadowglen 299	n.d.	n.d.	n.d.	n.d.	336	7	n.d.	n.d.	52
Three Hills RCA 144	n.d.	1	1.4	n.d.	203	32	n.d.	n.d.	26
Wetaskiwin	n.d.	n.d.	0.5	n.d.	327	91	0.1	n.d.	514
Gainhad 292	n.d.	n.d.	4.8	n.d.	205	32	0.2	n.d.	41
Airdrie 456	n.d.	[redacted]	n.d.	n.d.	161	197	0.2	n.d.	156
Metiskow 88-2	n.d.	6	n.d.	n.d.	862	16	n.d.	n.d.	27
Ferintosh OBS 147	n.d.	n.d.	n.d.	n.d.	24	20	n.d.	n.d.	63
Hardisty 1869	n.d.	2	n.d.	n.d.	1050	33	n.d.	n.d.	70
Metiskow 88-1	n.d.	2	3.9	0.14	1815	72	n.d.	n.d.	7316
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-	-	-	-	-	-	-	-	-

Table 3 (Cont'd...)

Statistical Parameter	Ag	Al	As	Au	B	Ba	Be	Bi	Br
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	0.03	1	0.3	0.03	24	5	0.03	0.03	26
Median	0.03	1	0.3	0.03	258	30	0.03	0.03	89
Max	0.03	322	7.5	0.14	1815	1186	0.22	0.03	29375
Mean	0.03	13	1.1	0.03	355	81	0.06	0.03	1099
Lower Quartile	0.03	1	0.3	0.03	195	17	0.03	0.03	50
Upper Quartile	0.03	5	1.0	0.03	362	73	0.07	0.03	195
95th Percentile	0.03	16	3.9	0.03	1068	198	0.21	0.03	1997
Standard Deviation	0.00	52	1.6	0.02	355	188	0.06	0.00	4734
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	0.00	16	0.5	0.01	110	58	0.02	0.00	1467

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Ca	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy
	µg/L	µg/L	µg/L	ppm	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	2165	0.15	n.d.	8	0.02	n.d.	0.09	n.d.	n.d.
Carseland	39017	0.17	n.d.	11	0.23	n.d.	0.03	0.3	n.d.
Irricana	4506	n.d.	n.d.	34	0.04	n.d.	0.04	0.3	n.d.
Wheatland Rosebud	3842	n.d.	0.02	29	0.20	0.6	0.09	1.5	n.d.
Hussar Well	26597	n.d.	n.d.	14	n.d.	n.d.	0.25	1.4	n.d.
Gull Lake 309	3310	n.d.	0.07	53	0.05	68.9	0.03	3.7	0.01
Warner 215	3053	n.d.	n.d.	72	0.15	3.1	0.04	0.3	n.d.
Warner 214	12118	n.d.	n.d.	1273	n.d.	5.4	0.16	n.d.	n.d.
Water Well #1	2056	n.d.	n.d.	22	0.04	n.d.	0.03	0.6	n.d.
Pine Lake 2688E	2909	n.d.	n.d.	3	n.d.	0.6	0.02	0.2	n.d.
Botanical Gardens 2327 OBS 160	2555	n.d.	n.d.	9	0.08	1.5	0.05	0.1	n.d.
Ministik Lake 2322E OBS 438	5749	n.d.	n.d.	20	0.22	3.1	0.08	0.2	n.d.
Edson Well	946	n.d.	n.d.	9	n.d.	0.5	0.04	0.1	n.d.
Drayton Valley 368	19176	0.18	n.d.	1	0.02	0.6	0.05	0.3	0.01
Water Well #2	1885	n.d.	0.90	30	0.14	1.0	0.04	0.1	0.10
Ponoka 60-2 144	73525	n.d.	n.d.	3	n.d.	1.0	0.15	0.3	n.d.
Warburg #2187E OBS 316	1240	n.d.	3.09	7	0.22	3.6	0.04	0.7	0.22
Dickson Dam 308	1507	n.d.	n.d.	3	0.02	7.2	n.d.	0.2	n.d.
Elnora #6 128	13611	n.d.	0.01	38	0.04	15.5	0.03	1.9	0.01
Water Well #3	2800	n.d.	0.01	10	0.10	12.1	0.05	0.3	n.d.
Donalda well	16474	n.d.	0.01	6	0.05	14.6	0.10	1.6	n.d.
Buffalo Lake OBS 4004C	194658	n.d.	0.07	4	0.49	12.6	0.01	1.9	n.d.
ALTA Public works #2	62353	n.d.	n.d.	1	0.05	13.3	0.10	5.4	n.d.
Halkirk Town well	13391	n.d.	n.d.	161	0.10	45.3	0.18	0.3	n.d.
Stettler 60-4 OBS 137	111360	n.d.	0.01	3	0.69	12.9	0.11	0.8	0.01
Handhills 1 OBS 124	2436	n.d.	0.09	10	0.08	14.6	0.02	0.2	0.01
Handhills 2 OBS 125	48686	n.d.	n.d.	3	0.06	8.8	n.d.	0.4	n.d.
Olds OBS 227	33698	n.d.	n.d.	4	0.05	14.0	0.04	2.2	n.d.
Olds OBS 126	33593	n.d.	n.d.	4	0.05	13.2	0.04	2.5	n.d.
Okotoks 2378E 217	26479	n.d.	n.d.	3	0.05	14.0	n.d.	0.6	n.d.
Pine Lake 398	1859	n.d.	0.01	1	0.02	9.6	0.01	0.4	n.d.
Meadowglen 299	10601	n.d.	n.d.	5	0.03	26.8	0.05	1.9	n.d.
Three Hills RCA 144	3319	n.d.	n.d.	13	n.d.	15.1	0.02	0.7	n.d.
Wetaskiwin	4450	n.d.	n.d.	69	0.09	22.1	0.04	0.4	n.d.
Galahad 292	112915	n.d.	0.01	2	0.09	14.7	n.d.	1.2	n.d.
Airdrie 456	5878	n.d.	0.59	41	0.17	17.7	0.04	0.3	0.06
Metiskow 88-2	2387	n.d.	0.96	1	0.12	18.7	0.03	0.6	0.09
Ferintosh OBS 147	137863	n.d.	0.02	n.d.	0.20	23.2	0.10	0.9	0.01
Hardisty 1869	2390	n.d.	0.34	6	0.03	10.5	0.01	0.1	0.04
Metiskow 88-1	2800	n.d.	n.d.	707	0.07	11.7	0.11	n.d.	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6									
Test well 4	-		-	-	-	-	-	-	-
Test well 5									

Table 3 (Cont'd...)

Field Site	Ca	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy
	µg/L	µg/L	µg/L	ppm	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	2165	0.15	n.d.	8	0.02	n.d.	0.09	n.d.	n.d.
Carseland	39017	0.17	n.d.	11	0.23	n.d.	0.03	0.3	n.d.
Irricana	4506	n.d.	n.d.	34	0.04	n.d.	0.04	0.3	n.d.
Wheatland Rosebud	3842	n.d.	0.02	29	0.20	0.6	0.09	1.5	n.d.
Hussar Well	26597	n.d.	n.d.	14	n.d.	n.d.	0.25	1.4	n.d.
Gull Lake 309	3310	n.d.	0.07	53	0.05	68.9	0.03	3.7	0.01
Warner 215	3053	n.d.	n.d.	72	0.15	3.1	0.04	0.3	n.d.
Warner 214	12118	n.d.	n.d.	[redacted]	n.d.	5.4	0.16	n.d.	n.d.
Water Well #1	2056	n.d.	n.d.	22	0.04	n.d.	0.03	0.6	n.d.
Pine Lake 2688E	2909	n.d.	n.d.	3	n.d.	0.6	0.02	0.2	n.d.
Botanical Gardens 2327 OBS 160	2555	n.d.	n.d.	9	0.08	1.5	0.05	0.1	n.d.
Ministik Lake 2322E OBS 438	5749	n.d.	n.d.	20	0.22	3.1	0.08	0.2	n.d.
Edson Well	946	n.d.	n.d.	9	n.d.	0.5	0.04	0.1	n.d.
Drayton Valley 368	19176	0.18	n.d.	1	0.02	0.6	0.05	0.3	0.01
Water Well #2	1885	n.d.	0.90	30	0.14	1.0	0.04	0.1	0.10
Ponoka 60-2 144	73525	n.d.	n.d.	3	n.d.	1.0	0.15	0.3	n.d.
Warburg #2187E OBS 316	1240	n.d.	3.09	7	0.22	3.6	0.04	0.7	0.22
Dickson Dam 308	1507	n.d.	n.d.	3	0.02	7.2	n.d.	0.2	n.d.
Elnora #6 128	13611	n.d.	0.01	38	0.04	15.5	0.03	1.9	0.01
Water Well #3	2800	n.d.	0.01	10	0.10	12.1	0.05	0.3	n.d.
Donalda well	16474	n.d.	0.01	6	0.05	14.6	0.10	1.6	n.d.
Buffalo Lake OBS 4004C	194658	n.d.	0.07	4	0.49	12.6	0.01	1.9	n.d.
ALTA Public works #2	62353	n.d.	n.d.	1	0.05	13.3	0.10	5.4	n.d.
Halkirk Town well	13391	n.d.	n.d.	161	0.10	45.3	0.18	0.3	n.d.
Stettler 60-4 OBS 137	111360	n.d.	0.01	3	0.69	12.9	0.11	0.8	0.01
Handhills 1 OBS 124	2436	n.d.	0.09	10	0.08	14.6	0.02	0.2	0.01
Handhills 2 OBS 125	48686	n.d.	n.d.	3	0.06	8.8	n.d.	0.4	n.d.
Olds OBS 227	33698	n.d.	n.d.	4	0.05	14.0	0.04	2.2	n.d.
Olds OBS 126	33593	n.d.	n.d.	4	0.05	13.2	0.04	2.5	n.d.
Okotoks 2378E217	26479	n.d.	n.d.	3	0.05	14.0	n.d.	0.6	n.d.
Pine Lake 398	1859	n.d.	0.01	1	0.02	9.6	0.01	0.4	n.d.
Meadowglen 299	10601	n.d.	n.d.	5	0.03	26.8	0.05	1.9	n.d.
Three Hills RCA 144	3319	n.d.	n.d.	13	n.d.	15.1	0.02	0.7	n.d.
Wetaskiwin	4450	n.d.	n.d.	69	0.09	22.1	0.04	0.4	n.d.
Galahad 292	112915	n.d.	0.01	2	0.09	14.7	n.d.	1.2	n.d.
Airdrie 456	5878	n.d.	0.59	41	0.17	17.7	0.04	0.3	0.06
Metiskow 88-2	2387	n.d.	0.96	1	0.12	18.7	0.03	0.6	0.09
Ferintosh OBS 147	137863	n.d.	0.02	n.d.	0.20	23.2	0.10	0.9	0.01
Hardisty 1869	2390	n.d.	0.34	6	0.03	10.5	0.01	0.1	0.04
Metiskow 88-1	2800	n.d.	n.d.	[redacted]	0.07	11.7	0.11	n.d.	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-	-	-	-	-	-	-	-	-

Table 3 (Cont'd...)

Statistical Parameter	Ca	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy
	µg/L	µg/L	µg/L	ppm	µg/L	µg/L	µg/L	µg/L	µg/L
Min	946	0.03	0.01	1	0.02	0.3	0.01	0.1	0.01
Median	5128	0.03	0.01	9	0.09	11.1	0.04	0.4	0.01
Max	194658	0.18	3.09	1273	0.69	68.9	0.25	5.4	0.22
Mean	26254	0.04	0.16	67	0.12	11.5	0.06	0.9	0.02
Lower Quartile	2525	0.03	0.01	3	0.05	1.0	0.03	0.2	0.01
Upper Quartile	28346	0.03	0.01	29	0.13	14.6	0.09	1.3	0.01
95th Percentile	114162	0.15	0.90	188	0.24	27.7	0.16	2.6	0.09
Standard Deviation	43212	0.04	0.53	226	0.13	13.2	0.05	1.1	0.04
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	13391	0.01	0.16	70	0.04	4.1	0.02	0.3	0.01

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Er	Eu	Fe	Ga	Gd	Ge	Hf	Hg	Ho
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	n.d.	41	n.d.	n.d.	0.06	n.d.	n.d.	n.d.
Carseland	n.d.	n.d.	424	n.d.	n.d.	0.17	n.d.	0.1	n.d.
Irricana	n.d.	n.d.	37	n.d.	n.d.	1.17	n.d.	0.1	n.d.
Wheatland Rosebud	n.d.	n.d.	63	n.d.	n.d.	0.61	n.d.	n.d.	n.d.
Hussar Well	n.d.	n.d.	318	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Gull Lake 309	n.d.	n.d.	347	0.27	0.01	0.19	n.d.	0.1	n.d.
Warner 215	n.d.	n.d.	n.d.0	n.d.	n.d.	0.16	n.d.	0.1	n.d.
Warner 214	n.d.	n.d.	255	n.d.	n.d.	1.05	n.d.	8.2	n.d.
Water Well #1	n.d.	n.d.	n.d.0	n.d.	n.d.	0.92	n.d.	0.3	n.d.
Pine Lake 2688E	n.d.	n.d.	17	n.d.	n.d.	n.d.	n.d.	0.2	n.d.
Botanical Gardens 2327 OBS 160	n.d.	n.d.	47	n.d.	n.d.	0.49	n.d.	0.1	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	43	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.0	n.d.	n.d.	1.37	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	56	n.d.	n.d.	0.10	n.d.	n.d.	n.d.
Water Well #2	0.04	0.01	22	0.11	0.11	0.91	n.d.	n.d.	0.01
Ponoka 60-2 144	n.d.	n.d.	359	n.d.	n.d.	0.09	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	0.11	0.08	46	0.10	0.32	0.29	n.d.	n.d.	0.04
Dickson Dam 308	n.d.	n.d.	13	n.d.	0.01	0.66	n.d.	0.2	n.d.
Elnora #6 128	0.01	n.d.	241	n.d.	n.d.	0.09	n.d.	n.d.	n.d.
Water Well #3	0.01	n.d.	16	n.d.	n.d.	1.52	n.d.	n.d.	n.d.
Donalda well	n.d.	n.d.	n.d.0	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
Buffalo Lake OBS 4004C	n.d.	n.d.	5226	n.d.	0.01	0.07	n.d.	n.d.	n.d.
ALTA Public works #2	n.d.	n.d.	745	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Halkirk Town well	n.d.	0.01	89	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	1611	n.d.	0.01	0.27	n.d.	0.1	n.d.
Handhills 1 OBS 124	0.01	n.d.	213	n.d.	0.01	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	0.01	n.d.0	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	567	n.d.	0.01	0.09	n.d.	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	277	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.	31	n.d.	0.01	0.08	n.d.	n.d.	n.d.
Pine Lake 398	n.d.	n.d.	11	n.d.	n.d.	0.85	n.d.	n.d.	n.d.
Meadowglen 299	0.01	n.d.	94	n.d.	n.d.	0.75	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.0	n.d.	n.d.	0.38	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	0.01	41	n.d.	n.d.	0.76	n.d.	n.d.	n.d.
Galahad 292	n.d.	n.d.	3380	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Airdrie 456	0.03	0.02	1036	0.10	0.08	6.47	0.02	n.d.	0.01
Metiskow 88-2	0.05	0.03	29	n.d.	0.13	0.08	n.d.	n.d.	0.02
Ferintosh OBS 147	0.01	n.d.	2096	n.d.	0.01	0.12	n.d.	n.d.	n.d.
Hardisty 1869	0.02	0.01	24	n.d.	0.05	0.46	n.d.	n.d.	0.01
Metiskow 88-1	n.d.	n.d.	50	n.d.	n.d.	n.d.	n.d.	0.5	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-								
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5									

Table 3 (Cont'd...)

Field Site	Er	Eu	Fe	Ga	Gd	Ge	Hf	Hg	Ho
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	n.d.	41	n.d.	n.d.	0.06	n.d.	n.d.	n.d.
Carseland	n.d.	n.d.	[redacted]	n.d.	n.d.	0.17	n.d.	0.1	n.d.
Irricana	n.d.	n.d.	37	n.d.	n.d.	1.17	n.d.	0.1	n.d.
Wheatland Rosebud	n.d.	n.d.	63	n.d.	n.d.	0.61	n.d.	n.d.	n.d.
Hussar Well	n.d.	n.d.	[redacted]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Gull Lake 309	n.d.	n.d.	[redacted]	0.27	0.01	0.19	n.d.	0.1	n.d.
Warner 215	n.d.	n.d.	n.d.0	n.d.	n.d.	0.16	n.d.	0.1	n.d.
Warner 214	n.d.	n.d.	255	n.d.	n.d.	1.05	n.d.	8.2	n.d.
Water Well #1	n.d.	n.d.	n.d.0	n.d.	n.d.	0.92	n.d.	0.3	n.d.
Pine Lake 2688E	n.d.	n.d.	17	n.d.	n.d.	n.d.	n.d.	0.2	n.d.
Botanical Gardens 2327 OBS 160	n.d.	n.d.	47	n.d.	n.d.	0.49	n.d.	0.1	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	43	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.0	n.d.	n.d.	1.37	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	56	n.d.	n.d.	0.10	n.d.	n.d.	n.d.
Water Well #2	0.04	0.01	22	0.11	0.11	0.91	n.d.	n.d.	0.01
Ponoka 60-2 144	n.d.	n.d.	[redacted]	n.d.	n.d.	0.09	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	0.11	0.08	46	0.10	0.32	0.29	n.d.	n.d.	0.04
Dickson Dam 308	n.d.	n.d.	13	n.d.	0.01	0.66	n.d.	0.2	n.d.
Elnora #6 128	0.01	n.d.	241	n.d.	n.d.	0.09	n.d.	n.d.	n.d.
Water Well #3	0.01	n.d.	16	n.d.	n.d.	1.52	n.d.	n.d.	n.d.
Donalda well	n.d.	n.d.	n.d.0	n.d.	n.d.	n.d.	n.d.	0.1	n.d.
Buffalo Lake OBS 4004C	n.d.	n.d.	[redacted]	n.d.	0.01	0.07	n.d.	n.d.	n.d.
ALTA Public works #2	n.d.	n.d.	[redacted]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Halkirk Town well	n.d.	0.01	89	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	[redacted]	n.d.	0.01	0.27	n.d.	0.1	n.d.
Handhills 1 OBS 124	0.01	n.d.	213	n.d.	0.01	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	0.01	n.d.0	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	[redacted]	n.d.	0.01	0.09	n.d.	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	277	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.	31	n.d.	0.01	0.08	n.d.	n.d.	n.d.
Pine Lake 398	n.d.	n.d.	11	n.d.	n.d.	0.85	n.d.	n.d.	n.d.
Meadowglen 299	0.01	n.d.	94	n.d.	n.d.	0.75	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.0	n.d.	n.d.	0.38	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	0.01	41	n.d.	n.d.	0.76	n.d.	n.d.	n.d.
Galahad 292	n.d.	n.d.	[redacted]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Airdrie 456	0.03	0.02	[redacted]	0.10	0.08	6.47	0.02	n.d.	0.01
Metiskow 88-2	0.05	0.03	29	n.d.	0.13	0.08	n.d.	n.d.	0.02
Ferintosh OBS 147	0.01	n.d.	[redacted]	n.d.	0.01	0.12	n.d.	n.d.	n.d.
Hardisty 1869	0.02	0.01	24	n.d.	0.05	0.46	n.d.	n.d.	0.01
Metiskow 88-1	n.d.	n.d.	50	n.d.	n.d.	n.d.	n.d.	0.5	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-		-	-				-	

Table 3 (Cont'd...)

Statistical Parameter	Er	Eu	Fe	Ga	Gd	Ge	Hf	Hg	Ho
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	0.01	0.01	5	0.03	0.01	0.03	0.01	0.1	0.01
Median	0.01	0.01	49	0.03	0.01	0.14	0.01	0.1	0.01
Max	0.11	0.08	5226	0.27	0.32	6.47	0.02	8.2	0.04
Mean	0.01	0.01	447	0.04	0.02	0.51	0.01	0.3	0.01
Lower Quartile	0.01	0.01	21	0.03	0.01	0.07	0.01	0.1	0.01
Upper Quartile	0.01	0.01	325	0.03	0.01	0.68	0.01	0.1	0.01
95th Percentile	0.04	0.02	2160	0.10	0.11	1.38	0.01	0.3	0.01
Standard Deviation	0.02	0.01	1019	0.04	0.06	1.05	0.00	1.3	0.01
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	0.01	0.00	316	0.01	0.02	0.33	0.00	0.4	0.00

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	n.d.	562	n.d.	54.7	n.d.	186	4.03	0.8
Carseland	n.d.	n.d.	2023	n.d.	19.5	n.d.	16261	256.64	7.3
Irricana	n.d.	n.d.	873	n.d.	27.6	n.d.	641	9.49	4.9
Wheatland Rosebud	n.d.	n.d.	882	0.01	91.5	n.d.	437	10.43	1.3
Hussar Well	n.d.	n.d.	1951	n.d.	389.9	n.d.	2596	21.71	n.d.
Gull Lake 309	n.d.	0.65	773	0.04	26.8	n.d.	236	1.49	31.0
Warner 215	n.d.	n.d.	1390	n.d.	28.3	n.d.	814	1.24	0.4
Warner 214	n.d.	n.d.	3775	n.d.	111.8	n.d.	5283	2.81	1.0
Water Well #1	n.d.	n.d.	815	n.d.	27.8	n.d.	566	2.37	2.9
Pine Lake 2688E	n.d.	n.d.	716	n.d.	48.7	n.d.	488	5.30	2.2
Botanical Gardens 2327 OBS 160	n.d.	n.d.	676	n.d.	49.8	n.d.	193	3.51	3.0
Ministik Lake 2322E OBS 438	n.d.	n.d.	2125	n.d.	99.1	n.d.	581	4.23	0.5
Edson Well	n.d.	n.d.	482	n.d.	17.0	n.d.	232	0.47	5.6
Drayton Valley 368	n.d.	n.d.	1257	n.d.	36.2	n.d.	6908	31.09	1.9
Water Well #2	n.d.	n.d.	597	0.40	30.3	n.d.	159	2.82	18.6
Ponoka 60-2 144	n.d.	n.d.	2924	0.01	60.9	n.d.	25673	58.55	0.7
Warburg #2187E OBS 316	n.d.	n.d.	557	1.43	17.1	0.01	111	4.74	3.0
Dickson Dam 308	n.d.	n.d.	1063	n.d.	40.4	n.d.	482	1.80	17.7
Elnora #6 128	n.d.	n.d.	2151	n.d.	83.1	n.d.	4609	22.03	3.3
Water Well #3	n.d.	n.d.	665	n.d.	69.5	n.d.	213	3.54	1.8
Donalda well	n.d.	n.d.	1772	0.01	97.6	n.d.	1905	10.67	0.9
Buffalo Lake OBS 4004C	n.d.	n.d.	2869	0.01	104.3	n.d.	45746	414.87	1.4
ALTA Public works #2	n.d.	n.d.	3152	n.d.	95.5	n.d.	23183	156.34	n.d.
Halkirk Town well	n.d.	n.d.	5981	n.d.	288.1	n.d.	1379	6.62	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	4690	0.01	82.1	n.d.	23351	255.55	0.9
Handhills 1 OBS 124	n.d.	n.d.	838	0.04	46.4	n.d.	321	16.68	8.3
Handhills 2 OBS 125	n.d.	n.d.	4479	n.d.	27.7	n.d.	41158	9.72	3.7
Olds OBS 227	n.d.	n.d.	3738	n.d.	81.5	n.d.	11022	50.80	7.3
Olds OBS 126	n.d.	n.d.	3633	n.d.	70.6	n.d.	11002	47.87	7.1
Okotoks 2378E217	n.d.	n.d.	2496	n.d.	26.8	n.d.	12998	18.21	5.7
Pine Lake 398	n.d.	n.d.	579	n.d.	27.4	n.d.	204	4.72	4.1
Meadowglen 299	n.d.	n.d.	1309	n.d.	81.1	n.d.	1247	20.27	1.0
Three Hills RCA 144	n.d.	n.d.	787	n.d.	31.4	n.d.	361	3.50	60.2
Wetaskiwin	n.d.	n.d.	774	n.d.	98.3	n.d.	377	9.74	5.0
Galahad 292	n.d.	n.d.	4472	n.d.	102.6	n.d.	32883	81.60	4.8
Airdrie 456	n.d.	n.d.	1331	0.26	41.8	n.d.	1477	17.02	15.0
Metiskow 88-2	n.d.	n.d.	2175	0.50	78.1	0.01	628	2.28	1.6
Ferintosh OBS 147	n.d.	n.d.	2456	0.01	204.1	n.d.	43033	205.68	0.3
Hardisty 1869	n.d.	n.d.	763	0.18	23.3	n.d.	350	1.89	2.2
Metiskow 88-1	n.d.	n.d.	2367	n.d.	50.5	n.d.	957	5.50	1.0
Cluny 5	-		-	-	-	-	-	-	-
Cluny 6									
Test well 4	-	-	-	-	-	-		-	-
Test well 5									

Table 3 (Cont'd...)

Field Site	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	n.d.	562	n.d.	54.7	n.d.	186	4.03	0.8
Carseland	n.d.	n.d.	2023	n.d.	19.5	n.d.	16261	[illegible]	7.3
Irricana	n.d.	n.d.	873	n.d.	27.6	n.d.	641	9.49	4.9
Wheatland Rosebud	n.d.	n.d.	882	0.01	91.5	n.d.	437	10.43	1.3
Hussar Well	n.d.	n.d.	1951	n.d.	389.9	n.d.	2596	21.71	n.d.
Gull Lake 309	n.d.	0.65	773	0.04	26.8	n.d.	236	1.49	31.0
Warner 215	n.d.	n.d.	1390	n.d.	28.3	n.d.	814	1.24	0.4
Warner 214	n.d.	n.d.	3775	n.d.	111.8	n.d.	5283	2.81	1.0
Water Well #1	n.d.	n.d.	815	n.d.	27.8	n.d.	566	2.37	2.9
Pine Lake 2688E	n.d.	n.d.	716	n.d.	48.7	n.d.	488	5.30	2.2
Botanical Gardens 2327 OBS 160	n.d.	n.d.	676	n.d.	49.8	n.d.	193	3.51	3.0
Ministik Lake 2322E OBS 438	n.d.	n.d.	2125	n.d.	99.1	n.d.	581	4.23	0.5
Edson Well	n.d.	n.d.	482	n.d.	17.0	n.d.	232	0.47	5.6
Drayton Valley 368	n.d.	n.d.	1257	n.d.	36.2	n.d.	6908	31.09	1.9
Water Well #2	n.d.	n.d.	597	0.40	30.3	n.d.	159	2.82	18.6
Ponoka 60-2 144	n.d.	n.d.	2924	0.01	60.9	n.d.	25673	[illegible]	0.7
Warburg #2187E OBS 316	n.d.	n.d.	557	1.43	17.1	0.01	111	4.74	3.0
Dickson Dam 308	n.d.	n.d.	1063	n.d.	40.4	n.d.	482	1.80	17.7
Elnora #6 128	n.d.	n.d.	2151	n.d.	83.1	n.d.	4609	22.03	3.3
Water Well #3	n.d.	n.d.	665	n.d.	69.5	n.d.	213	3.54	1.8
Donalda well	n.d.	n.d.	1772	0.01	97.6	n.d.	1905	10.67	0.9
Buffalo Lake OBS 4004C	n.d.	n.d.	2869	0.01	104.3	n.d.	45746	[illegible]	1.4
ALTA Public works #2	n.d.	n.d.	3152	n.d.	95.5	n.d.	23183	[illegible]	n.d.
Halkirk Town well	n.d.	n.d.	5981	n.d.	288.1	n.d.	1379	6.62	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	4690	0.01	82.1	n.d.	23351	[illegible]	0.9
Handhills 1 OBS 124	n.d.	n.d.	838	0.04	46.4	n.d.	321	16.68	8.3
Handhills 2 OBS 125	n.d.	n.d.	4479	n.d.	27.7	n.d.	41158	9.72	3.7
Olds OBS 227	n.d.	n.d.	3738	n.d.	81.5	n.d.	11022	[illegible]	7.3
Olds OBS 126	n.d.	n.d.	3633	n.d.	70.6	n.d.	11002	47.87	7.1
Okotoks 2378E217	n.d.	n.d.	2496	n.d.	26.8	n.d.	12998	18.21	5.7
Pine Lake 398	n.d.	n.d.	579	n.d.	27.4	n.d.	204	4.72	4.1
Meadowglen 299	n.d.	n.d.	1309	n.d.	81.1	n.d.	1247	20.27	1.0
Three Hills RCA 144	n.d.	n.d.	787	n.d.	31.4	n.d.	361	3.50	60.2
Wetaskiwin	n.d.	n.d.	774	n.d.	98.3	n.d.	377	9.74	5.0
Galahad 292	n.d.	n.d.	4472	n.d.	102.6	n.d.	32883	[illegible]	4.8
Airdrie 456	n.d.	n.d.	1331	0.26	41.8	n.d.	1477	17.02	15.0
Metiskow 88-2	n.d.	n.d.	2175	0.50	78.1	0.01	628	2.28	1.6
Ferintosh OBS 147	n.d.	n.d.	2456	0.01	204.1	n.d.	43033	[illegible]	0.3
Hardisty 1869	n.d.	n.d.	963	0.18	23.3	n.d.	350	1.89	2.2
Metiskow 88-1	n.d.	n.d.	2367	n.d.	50.5	n.d.	957	5.50	1.0
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-	-	-	-	-	-	-	-	-

Table 3 (Cont'd...)

Statistical Parameter	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	0.01	0.03	482	0.01	17.0	0.01	111	0.47	0.3
Median	0.01	0.03	1361	0.01	52.6	0.01	886	9.61	3.0
Max	0.01	0.65	5981	1.43	389.9	0.01	45746	414.87	60.2
Mean	0.01	0.04	1928	0.08	74.7	0.01	8006	44.70	6.4
Lower Quartile	0.01	0.03	784	0.01	28.2	0.01	358	3.51	1.0
Upper Quartile	0.01	0.03	2589	0.01	92.5	0.01	11007	24.30	5.7
95th Percentile	0.01	0.03	4490	0.41	208.3	0.01	41252	255.60	21.1
Standard Deviation	0.00	0.10	1403	0.24	72.7	0.00	13098	89.02	11.0
# Samples	40	40	40	40	40	40	40	40	37
95% Confidence	0.00	0.03	435	0.08	22.5	0.00	4059	27.59	3.6

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr
	ppm	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	231	n.d.	n.d.	n.d.	n.d.	320	n.d.	n.d.	n.d.
Carseland	217	n.d.	n.d.	0.3	n.d.	n.d.	n.d.	n.d.	n.d.
Irricana	359	n.d.	n.d.	n.d.	n.d.	29	n.d.	n.d.	n.d.
Wheatland Rosebud	396	n.d.	0.01	0.6	n.d.	89	0.3	0.2	n.d.
Hussar Well	989	n.d.	n.d.	n.d.	n.d.	n.d.	2.2	n.d.	n.d.
Gull Lake 309	292	0.03	0.04	2.5	n.d.	26	0.2	n.d.	0.01
Warner 215	573	0.01	0.03	n.d.	n.d.	66	0.1	n.d.	n.d.
Warner 214	1820	n.d.	1.58	n.d.	n.d.	n.d.	1.4	n.d.	n.d.
Water Well #1	317	0.01	0.07	0.6	n.d.	98	0.1	n.d.	n.d.
Pine Lake 2688E	340	n.d.	0.03	n.d.	n.d.	57	n.d.	n.d.	n.d.
Botanical Gardens 2327 OBS 160	339	n.d.	0.01	n.d.	n.d.	127	n.d.	0.2	n.d.
Ministik Lake 2322E OBS 438	515	n.d.	n.d.	n.d.	n.d.	252	n.d.	0.2	n.d.
Edson Well	252	n.d.	n.d.	n.d.	n.d.	63	n.d.	n.d.	n.d.
Drayton Valley 368	319	n.d.	0.01	0.6	n.d.	n.d.	0.1	n.d.	n.d.
Water Well #2	285	0.01	0.53	0.4	n.d.	139	0.1	n.d.	0.13
Ponoka 60-2 144	233	n.d.	0.01	n.d.	n.d.	28	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	207	-	1.72	0.7	n.d.	196	0.4	n.d.	0.40
Dickson Dam 308	264	-	n.d.	1.5	n.d.	53	0.1	n.d.	n.d.
Elnora #6 128	630	-	0.01	n.d.	n.d.	20	n.d.	n.d.	n.d.
Water Well #3	348	-	n.d.	n.d.	n.d.	99	n.d.	n.d.	n.d.
Donalda well	432	-	n.d.	0.3	n.d.	127	0.2	n.d.	n.d.
Buffalo Lake OBS 40040	192	-	0.02	n.d.	n.d.	34	n.d.	n.d.	n.d.
ALTA Public works #2	148	-	0.01	n.d.	n.d.	26	0.3	n.d.	n.d.
Halkirk Town well	706	-	0.02	0.4	n.d.	297	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	95	-	0.02	1.3	n.d.	27	n.d.	n.d.	n.d.
Handhills 1 OBS 124	240	-	0.05	0.5	n.d.	202	0.1	n.d.	0.01
Handhills 2 OBS 125	34	-	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	452	-	0.01	n.d.	n.d.	29	n.d.	0.2	n.d.
Olds OBS 126	444	-	0.01	n.d.	n.d.	29	n.d.	n.d.	n.d.
Okotoks 2378E 217	214	-	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pine Lake 398	238	-	n.d.	n.d.	n.d.	55	n.d.	n.d.	n.d.
Meadowglen 299	648	-	n.d.	n.d.	n.d.	37	n.d.	n.d.	n.d.
Three Hills RCA 144	335	-	n.d.	0.2	n.d.	37	n.d.	n.d.	n.d.
Wetaskiwin	399	-	0.01	0.2	n.d.	56	n.d.	n.d.	n.d.
Galahad 292	106	-	n.d.	n.d.	n.d.	33	n.d.	n.d.	n.d.
Airdrie 456	319	-	0.33	0.6	n.d.	90	0.1	n.d.	0.08
Metiskow 88-2	309	-	0.51	0.3	n.d.	203	0.2	n.d.	0.12
Ferintosh OBS 147	93	-	0.02	n.d.	n.d.	n.d.0	n.d.	n.d.	n.d.
Hardisty 1869	165	-	0.17	n.d.	n.d.	457	n.d.	n.d.	0.05
Metiskow 88-1	635	-	0.08	n.d.	n.d.	152	n.d.	n.d.	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6									
Test well 4	-	-	-	-	-	-		-	-
Test well 5									

Table 3 (Cont'd...)

Field Site	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr
	ppm	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	[illegible]	n.d.	n.d.	n.d.	n.d.	320	n.d.	n.d.	n.d.
Carseland	[illegible]	n.d.	n.d.	0.3	n.d.	n.d.	n.d.	n.d.	n.d.
Irricana	[illegible]	n.d.	n.d.	n.d.	n.d.	29	n.d.	n.d.	n.d.
Wheatland Rosebud	[illegible]	n.d.	0.01	0.6	n.d.	89	0.3	0.2	n.d.
Hussar Well	[illegible]	n.d.	n.d.	n.d.	n.d.	n.d.	2.2	n.d.	n.d.
Gull Lake 309	[illegible]	0.03	0.04	2.5	n.d.	26	0.2	n.d.	0.01
Warner 215	[illegible]	0.01	0.03	n.d.	n.d.	66	0.1	n.d.	n.d.
Warner 214	[illegible]	n.d.	1.58	n.d.	n.d.	n.d.	1.4	n.d.	n.d.
Water Well #1	[illegible]	0.01	0.07	0.6	n.d.	98	0.1	n.d.	n.d.
Pine Lake 2688E	[illegible]	n.d.	0.03	n.d.	n.d.	57	n.d.	n.d.	n.d.
Botanical Gardens 2327 OBS 160	[illegible]	n.d.	0.01	n.d.	n.d.	127	n.d.	0.2	n.d.
Ministik Lake 2322E OBS 438	[illegible]	n.d.	n.d.	n.d.	n.d.	252	n.d.	0.2	n.d.
Edson Well	[illegible]	n.d.	n.d.	n.d.	n.d.	63	n.d.	n.d.	n.d.
Drayton Valley 368	[illegible]	n.d.	0.01	0.6	n.d.	n.d.	0.1	n.d.	n.d.
Water Well #2	[illegible]	0.01	0.53	0.4	n.d.	139	0.1	n.d.	0.13
Ponoka 60-2 144	[illegible]	n.d.	0.01	n.d.	n.d.	28	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	[illegible]	-	1.72	0.7	n.d.	196	0.4	n.d.	0.40
Dickson Dam 308	[illegible]	-	n.d.	1.5	n.d.	53	0.1	n.d.	n.d.
Elnora #6 128	[illegible]	-	0.01	n.d.	n.d.	20	n.d.	n.d.	n.d.
Water Well #3	[illegible]	-	n.d.	n.d.	n.d.	99	n.d.	n.d.	n.d.
Donalda well	[illegible]	-	n.d.	0.3	n.d.	127	0.2	n.d.	n.d.
Buffalo Lake OBS 4004C	192	-	0.02	n.d.	n.d.	34	n.d.	n.d.	n.d.
ALTA Public works #2	148	-	0.01	n.d.	n.d.	26	0.3	n.d.	n.d.
Halkirk Town well	[illegible]	-	0.02	0.4	n.d.	297	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	95	-	0.02	1.3	n.d.	27	n.d.	n.d.	n.d.
Handhills 1 OBS 124	[illegible]	-	0.05	0.5	n.d.	202	0.1	n.d.	0.01
Handhills 2 OBS 125	34	-	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	[illegible]	-	0.01	n.d.	n.d.	29	n.d.	0.2	n.d.
Olds OBS 126	[illegible]	-	0.01	n.d.	n.d.	29	n.d.	n.d.	n.d.
Okotoks 2378E217	[illegible]	-	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pine Lake 398	[illegible]	-	n.d.	n.d.	n.d.	55	n.d.	n.d.	n.d.
Meadowglen 299	[illegible]	-	n.d.	n.d.	n.d.	37	n.d.	n.d.	n.d.
Three Hills RCA 144	[illegible]	-	n.d.	0.2	n.d.	37	n.d.	n.d.	n.d.
Wetaskiwin	[illegible]	-	0.01	0.2	n.d.	56	n.d.	n.d.	n.d.
Galahad 292	106	-	n.d.	n.d.	n.d.	33	n.d.	n.d.	n.d.
Airdrie 456	[illegible]	-	0.33	0.6	n.d.	90	0.1	n.d.	0.08
Metiskow 88-2	[illegible]	-	0.51	0.3	n.d.	203	0.2	n.d.	0.12
Ferintosh OBS 147	93	-	0.02	n.d.	n.d.	n.d.0	n.d.	n.d.	n.d.
Hardisty 1869	165	-	0.17	n.d.	n.d.	457	n.d.	n.d.	0.05
Metiskow 88-1	[illegible]	-	0.08	n.d.	n.d.	152	n.d.	n.d.	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-	-	-	-	-	-	-	-	-

Table 3 (Cont'd...)

Statistical Parameter	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr
	ppm	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	34.067	0.01	0.01	0.1	0.03	1	0.1	0.1	0.01
Median	317.766	0.01	0.01	0.1	0.03	54	0.1	0.1	0.01
Max	########	0.03	1.72	2.5	0.03	457	2.2	0.2	0.40
Mean	378.277	0.01	0.13	0.3	0.03	90	0.2	0.1	0.02
Lower Quartile	227.860	0.01	0.01	0.1	0.03	27	0.1	0.1	0.01
Upper Quartile	435.047	0.01	0.03	0.4	0.03	127	0.1	0.1	0.01
95th Percentile	720.600	0.02	0.58	1.3	0.03	298	0.4	0.2	0.12
Standard Deviation	301.688	0.01	0.37	0.5	0.00	101	0.4	0.0	0.07
# Samples	40	16	40	40	40	40	40	40	40
95% Confidence	93.492	0.00	0.12	0.1	0.00	31	0.1	0.0	0.02

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Pt	Rb	Re	Rh	Ru	S	Sb	Sc	Se
	µg/L	µg/L	µg/L	µg/L	µg/L	ppm	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	1.34	n.d.	n.d.	n.d.	1	n.d.	1	n.d.
Carseland	n.d.	0.50	0.04	n.d.	n.d.	95	0.1	1	0.5
Irricana	n.d.	0.72	n.d.	n.d.	n.d.	105	n.d.	1	0.7
Wheatland Rosebud	n.d.	1.46	n.d.	n.d.	n.d.	22	0.2	1	0.5
Hussar Well	n.d.	5.67	n.d.	n.d.	n.d.	438	n.d.	n.d.	n.d.
Gull Lake 309	n.d.	0.78	n.d.	n.d.	n.d.	2	1.5	2	1.0
Warner 215	n.d.	1.39	n.d.	n.d.	n.d.	108	0.1	1	4.1
Warner 214	n.d.	3.78	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	70.1
Water Well #1	n.d.	0.72	n.d.	n.d.	n.d.	13	n.d.	1	n.d.
Pine Lake 2688E	n.d.	0.58	n.d.	n.d.	n.d.	63	n.d.	1	n.d.
Botanical Gardens 2327 OBS 160	n.d.	1.45	n.d.	n.d.	n.d.	n.d.	n.d.	1	0.5
Ministik Lake 2322E OBS 438	n.d.	8.47	n.d.	n.d.	n.d.	12	n.d.	2	0.6
Edson Well	n.d.	0.69	n.d.	n.d.	n.d.	5	n.d.	1	n.d.
Drayton Valley 368	n.d.	1.40	n.d.	n.d.	n.d.	79	0.1	1	n.d.
Water Well #2	n.d.	1.05	n.d.	n.d.	n.d.	n.d.	n.d.	1	0.6
Ponoka 60-2 144	n.d.	4.29	n.d.	n.d.	n.d.	91	n.d.	1	n.d.
Warburg #2187E OBS 316	n.d.	0.76	n.d.	n.d.	n.d.	1	0.1	1	n.d.
Dickson Dam 308	n.d.	0.60	n.d.	n.d.	n.d.	6	2.3	1	n.d.
Elnora #6 128	n.d.	1.30	0.12	n.d.	n.d.	204	0.1	1	0.9
Water Well #3	n.d.	1.17	n.d.	n.d.	n.d.	20	n.d.	1	2.3
Donalda well	n.d.	4.01	n.d.	n.d.	n.d.	109	n.d.	2	0.5
Buffalo Lake OBS 4004C	n.d.	4.02	n.d.	n.d.	n.d.	156	n.d.	2	1.0
ALTA Public works #2	0.01	4.62	n.d.	0.01	n.d.	18	n.d.	3	n.d.
Halkirk Town well	n.d.	16.40	n.d.	n.d.	n.d.	1	n.d.	4	12.4
Stettler 60-4 OBS 137	n.d.	6.62	0.06	0.01	n.d.	47	n.d.	2	0.5
Handhills 1 OBS 124	n.d.	1.47	n.d.	n.d.	n.d.	n.d.	n.d.	1	0.9
Handhills 2 OBS 125	n.d.	0.21	0.04	n.d.	n.d.	9	n.d.	2	6.5
Olds OBS 227	0.01	2.29	n.d.	n.d.	n.d.	238	n.d.	1	0.8
Olds OBS 126	0.01	2.18	n.d.	n.d.	n.d.	216	n.d.	1	0.6
Okotoks 2378E217	n.d.	0.47	0.15	n.d.	n.d.	27	0.2	1	5.7
Pine Lake 398	n.d.	0.45	n.d.	n.d.	n.d.	37	n.d.	1	n.d.
Meadowglen 299	n.d.	1.35	n.d.	n.d.	n.d.	182	n.d.	2	n.d.
Three Hills RCA 144	n.d.	0.54	0.05	n.d.	n.d.	45	0.2	1	n.d.
Wetaskiwin	n.d.	1.26	n.d.	n.d.	n.d.	36	n.d.	2	4.0
Galahad 292	n.d.	1.27	n.d.	n.d.	n.d.	81	n.d.	3	0.5
Airdrie 456	n.d.	0.90	n.d.	n.d.	n.d.	22	n.d.	1	2.2
Metiskow 88-2	n.d.	2.01	n.d.	n.d.	n.d.	41	n.d.	1	0.6
Ferintosh OBS 147	n.d.	6.28	n.d.	n.d.	n.d.	56	n.d.	3	0.6
Hardisty 1869	n.d.	0.88	n.d.	n.d.	n.d.	2	n.d.	1	0.7
Metiskow 88-1	n.d.	2.71	n.d.	n.d.	n.d.	n.d.	n.d.	1	57.4
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-	-	-	-	-	-	-	-	-

Table 3 (Cont'd...)

Statistical Parameter	Pt	Rb	Re	Rh	Ru	S	Sb	Sc	Se
	µg/L	µg/L	µg/L	µg/L	µg/L	ppm	µg/L	µg/L	µg/L
Min	0.01	0.21	0.01	0.01	0.03	1	0.0	1	0.3
Median	0.01	1.35	0.01	0.01	0.03	32	0.0	1	0.6
Max	0.01	16.40	0.15	0.01	0.03	438	2.3	4	70.1
Mean	0.01	2.45	0.02	0.01	0.03	65	0.1	1	4.5
Lower Quartile	0.01	0.75	0.01	0.01	0.03	4	0.0	1	0.3
Upper Quartile	0.01	2.98	0.01	0.01	0.03	92	0.0	2	1.0
95th Percentile	0.01	6.71	0.06	0.01	0.03	217	0.3	3	14.6
Standard Deviation	0.00	3.00	0.03	0.00	0.00	89	0.4	1	14.0
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	0.00	0.93	0.01	0.00	0.00	28	0.1	0	4.3

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Si	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	3424	n.d.	n.d.	31.07	n.d.	n.d.	n.d.	n.d.	n.d.
Carseland	3187	n.d.	n.d.	294.74	n.d.	n.d.	n.d.	n.d.	n.d.
Irricana	3026	n.d.	n.d.	90.47	n.d.	n.d.	n.d.	n.d.	n.d.
Wheatland Rosebud	3529	n.d.	n.d.	89.28	n.d.	n.d.	n.d.	n.d.	n.d.
Hussar Well	4377	n.d.	n.d.	484.58	n.d.	n.d.	n.d.	n.d.	n.d.
Gull Lake 309	5906	n.d.	0.08	74.60	0.02	n.d.	n.d.	n.d.	n.d.
Warner 215	3360	n.d.	n.d.	190.72	n.d.	n.d.	n.d.	n.d.	n.d.
Warner 214	4451	n.d.	n.d.	1652.29	n.d.	n.d.	n.d.	n.d.	n.d.
Water Well #1	3115	n.d.	n.d.	71.47	n.d.	n.d.	n.d.	n.d.	n.d.
Pine Lake 2688E	3490	n.d.	0.16	63.46	n.d.	n.d.	n.d.	n.d.	n.d.
Botanical Gardens 2327 OBS 160	3618	n.d.	n.d.	50.12	n.d.	n.d.	n.d.	n.d.	n.d.
Ministik Lake 2322E OBS 438	9443	n.d.	n.d.	94.39	n.d.	n.d.	n.d.	n.d.	n.d.
Edson Well	3025	n.d.	n.d.	31.94	n.d.	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	4333	n.d.	n.d.	253.13	n.d.	n.d.	n.d.	n.d.	n.d.
Water Well #2	3808	0.12	n.d.	40.59	n.d.	0.02	n.d.	0.21	n.d.
Ponoka 60-2 144	5539	n.d.	n.d.	1670.24	n.d.	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	3197	0.35	n.d.	26.33	n.d.	0.04	n.d.	1.20	19
Dickson Dam 308	1620	n.d.	0.11	56.14	n.d.	n.d.	n.d.	0.07	n.d.
Elnora #6 128	4126	n.d.	n.d.	504.81	n.d.	n.d.	n.d.	n.d.	n.d.
Water Well #3	3417	n.d.	0.14	56.04	n.d.	n.d.	n.d.	n.d.	n.d.
Donalda well	8814	n.d.	n.d.	161.00	n.d.	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	6697	n.d.	n.d.	1439.08	n.d.	n.d.	n.d.	n.d.	n.d.
ALTA Public works #2	8970	n.d.	n.d.	1067.89	n.d.	n.d.	n.d.	n.d.	n.d.
Halkirk Town well	11925	n.d.	0.09	156.81	n.d.	n.d.	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	7564	n.d.	n.d.	1213.42	n.d.	n.d.	n.d.	n.d.	n.d.
Handhills 1 OBS 124	4162	n.d.	0.12	31.76	n.d.	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	8038	n.d.	n.d.	596.43	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	3778	n.d.	0.16	808.44	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 126	3455	n.d.	n.d.	795.92	n.d.	n.d.	n.d.	n.d.	n.d.
Okotoks 2378E217	3041	n.d.	0.06	467.97	n.d.	n.d.	n.d.	n.d.	n.d.
Pine Lake 398	2989	n.d.	n.d.	38.13	n.d.	n.d.	n.d.	n.d.	n.d.
Meadowglen 299	4075	n.d.	n.d.	256.52	n.d.	n.d.	n.d.	n.d.	n.d.
Three Hills RCA 144	3071	n.d.	n.d.	69.82	n.d.	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	3780	n.d.	n.d.	82.93	n.d.	n.d.	n.d.	n.d.	n.d.
Galahad 292	8722	n.d.	n.d.	898.36	n.d.	n.d.	n.d.	n.d.	n.d.
Airdrie 456	3661	0.09	n.d.	80.48	n.d.	0.01	n.d.	0.11	n.d.
Metiskow 88-2	3535	0.11	n.d.	55.15	n.d.	0.02	0.06	0.26	53
Ferintosh OBS 147	9674	n.d.	n.d.	795.88	n.d.	n.d.	n.d.	n.d.	n.d.
Hardisty 1869	3621	0.05	n.d.	37.39	n.d.	0.01	n.d.	n.d.	22
Metiskow 88-1	3722	n.d.	n.d.	132.39	n.d.	n.d.	n.d.	n.d.	n.d.
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-		-		-	-		-	
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5	-		-						

Table 3 (Cont'd...)

Statistical Parameter	Si	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	1620	0.01	0.03	26.33	0.01	0.01	0.03	0.03	1
Median	3750	0.01	0.03	113.39	0.01	0.01	0.03	0.03	5
Max	11925	0.35	0.16	1670.24	0.02	0.04	0.06	1.20	53
Mean	4832	0.03	0.04	375.30	0.01	0.01	0.03	0.07	7
Lower Quartile	3403	0.01	0.03	56.12	0.01	0.01	0.03	0.03	5
Upper Quartile	5631	0.01	0.03	527.72	0.01	0.01	0.03	0.03	5
95th Percentile	9455	0.11	0.14	1449.74	0.01	0.02	0.03	0.21	19
Standard Deviation	2402	0.06	0.04	473.95	0.00	0.01	0.01	0.19	8
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	744	0.02	0.01	146.88	0.00	0.00	0.00	0.06	3

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 3 (Cont'd...)

Field Site	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Cluny 85-1	n.d.	n.d.	n.d.	n.d.	1.20	0.01	n.d.	7	0.05
Carseland	n.d.	n.d.	3.20	n.d.	0.22	0.01	n.d.	12	n.d.
Irricana	n.d.	n.d.	0.11	0.2	0.28	0.01	n.d.	n.d.	0.04
Wheatland Rosebud	n.d.	n.d.	0.09	0.4	0.12	0.02	n.d.	8	0.42
Hussar Well	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.74
Gull Lake 309	n.d.	n.d.	0.25	0.5	2.10	0.03	n.d.	n.d.	0.11
Warner 215	n.d.	n.d.	0.02	0.6	0.29	0.01	n.d.	n.d.	0.03
Warner 214	n.d.	n.d.	n.d.	14.4	0.24	n.d.	n.d.	11	4.52
Water Well #1	n.d.	n.d.	0.05	0.3	0.91	0.02	n.d.	8	0.12
Pine Lake 2688E	n.d.	n.d.	0.04	n.d.	0.97	0.02	n.d.	n.d.	0.11
Botanical Gardens 2327 OBS 160	n.d.	n.d.	n.d.	n.d.	0.60	0.03	0.01	1	0.13
Ministik Lake 2322E OBS 438	n.d.	n.d.	0.02	0.2	0.03	0.01	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	0.05	n.d.	0.65	0.02	n.d.	1	0.02
Drayton Valley 368	n.d.	n.d.	1.33	n.d.	0.05	0.05	0.01	12	0.23
Water Well #2	n.d.	n.d.	0.03	0.4	0.36	0.44	0.03	2	0.08
Ponoka 60-2 144	n.d.	n.d.	0.05	n.d.	0.04	0.02	n.d.	1	0.12
Warburg #2187E OBS 316	n.d.	0.02	0.14	0.4	1.21	1.14	0.07	3	0.33
Dickson Dam 308	n.d.	n.d.	0.45	n.d.	0.24	0.01	n.d.	1	0.06
Elnora #6 128	n.d.	n.d.	0.13	0.2	0.12	0.03	n.d.	1	0.36
Water Well #3	n.d.	n.d.	0.02	n.d.	0.29	0.05	n.d.	n.d.	0.28
Donalda well	n.d.	n.d.	0.12	0.2	0.20	0.01	0.01	6	0.03
Buffalo Lake OBS 4004C	n.d.	n.d.	1.46	n.d.	0.05	0.06	0.01	3	0.09
ALTA Public works #2	n.d.	n.d.	n.d.	n.d.	0.03	0.02	n.d.	13	n.d.
Halkirk Town well	n.d.	n.d.	n.d.	0.9	0.02	0.02	n.d.	7	0.31
Stettler 60-4 OBS 137	n.d.	n.d.	0.12	n.d.	0.03	0.07	0.01	5	0.11
Handhills 1 OBS 124	n.d.	n.d.	0.02	n.d.	0.09	0.04	n.d.	1	0.04
Handhills 2 OBS 125	n.d.	n.d.	6.41	n.d.	0.05	0.02	n.d.	2	n.d.
Olds OBS 227	n.d.	n.d.	0.07	n.d.	0.03	0.02	n.d.	1	0.07
Olds OBS 126	n.d.	n.d.	0.05	n.d.	0.03	0.02	n.d.	1	0.07
Okotoks 2378E217	n.d.	n.d.	4.24	n.d.	n.d.	0.01	n.d.	2	n.d.
Pine Lake 398	n.d.	n.d.	0.05	n.d.	1.17	0.02	n.d.	n.d.	0.02
Meadowglen 299	n.d.	n.d.	0.29	n.d.	0.10	0.04	n.d.	1	0.62
Three Hills RCA 144	n.d.	n.d.	0.65	n.d.	0.12	0.01	n.d.	1	0.05
Wetaskiwin	n.d.	n.d.	0.12	0.2	0.12	0.05	0.01	n.d.	0.36
Galahad 292	n.d.	n.d.	0.31	n.d.	n.d.	0.03	n.d.	1	0.02
Airdrie 456	n.d.	n.d.	0.20	0.6	0.25	0.31	0.02	2	0.42
Metiskow 88-2	n.d.	0.01	0.65	n.d.	0.15	0.48	0.04	n.d.	0.98
Ferintosh OBS 147	n.d.	n.d.	0.11	n.d.	0.07	0.11	0.01	2	0.29
Hardisty 1869	n.d.	n.d.	0.04	n.d.	0.28	0.17	0.01	n.d.	0.35
Metiskow 88-1	n.d.	n.d.	n.d.	4.0	0.28	0.02	n.d.	n.d.	0.02
Cluny 5	-	-	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-	-	-
Test well 4	-	-	-	-	-	-	-	-	-
Test well 5									

Table 3 (Cont'd...)

Statistical Parameter	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0	0.01
Median	0.01	0.01	0.08	0.1	0.14	0.02	0.01	1	0.10
Max	0.01	0.02	6.41	14.4	2.10	1.14	0.07	13	4.52
Mean	0.01	0.01	0.52	0.7	0.33	0.09	0.01	3	0.32
Lower Quartile	0.01	0.01	0.02	0.1	0.05	0.01	0.01	0	0.03
Upper Quartile	0.01	0.01	0.26	0.2	0.29	0.05	0.01	3	0.32
95th Percentile	0.01	0.01	3.25	1.1	1.20	0.44	0.03	12	1.02
Standard Deviation	0.00	0.00	1.28	2.3	0.45	0.20	0.01	4	0.75
# Samples	40	40	40	40	40	40	40	40	40
95% Confidence	0.00	0.00	0.40	0.7	0.14	0.06	0.00	1	0.23

n.d. Not Detected
- Sample Not Available

Values above MAC guidelines
Values above AO guidelines

Table 4 Chromium speciation in groundwater samples in Alberta, Canada

Field Site	Chromium $^{3+}$	Chromium $^{6+}$
	µg/L	µg/L
Cluny 85-1	n.d.	n.d.
Carseland	n.d.	n.d.
Irricana	n.d.	n.d.
Wheatland Rosebud	n.d.	n.d.
Hussar Well	n.d.	n.d.
Gull Lake 309	n.d.	n.d.
Warner 215	n.d.	n.d.
Warner 214	n.d.	n.d.
Water Well #1	n.d.	n.d.
Pine Lake 2688E	n.d.	n.d.
Botanical Gardens 2327 OBS 160	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.
Edson Well	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.
Water Well #2	0.002	n.d.
Ponoka 60-2 144	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	n.d.
Dickson Dam 308	n.d.	n.d.
Elnora #6 128	n.d.	n.d.
Water Well #3	n.d.	n.d.
Donalda well	n.d.	n.d.
Buffalo Lake OBS 4004C	n.d.	n.d.
ALTA Public works #2	n.d.	n.d.
Halkirk Town well	n.d.	n.d.
Stettler 60-4 OBS 137	0.001	n.d.
Handhills 1 OBS 124	n.d.	n.d.
Handhills 2 OBS 125	n.d.	n.d.
Olds OBS 227	n.d.	n.d.
Olds OBS 126	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.
Pine Lake 398	n.d.	0.001
Meadowglen 299	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.
Wetaskiwin	n.d.	0.006
Galahad 292	n.d.	n.d.
Airdrie 456	n.d.	n.d.
Metiskow 88-2	n.d.	n.d.
Ferintosh OBS 147	n.d.	n.d.
Hardisty 1869	n.d.	n.d.
Metiskow 88-1	n.d.	n.d.
Cluny 5	-	-
Cluny 6		
Test well 4	-	-
Test well 5		

4.1.5 *Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)*

BTEX data for forty groundwater samples are summarized in Table 5. The concentrations of benzene, ethylbenzene, and xylenes in all samples were below the detection limit, with the exception of one sample that contained 0.0006 mg/L of xylene. Toluene was detected in 18 of the 40 samples, but only one sample (Dickson Dam 308: 0.085 mg/L) exceeded the aesthetic objective outlined in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006). The remaining 22 samples were characterized by toluene concentrations of less than the detection limit. This finding was consistent with a USGS survey that reported very low concentrations of toluene in several major aquifers as well as municipal and domestic water supplies throughout the United States (Zogorski et al. 2006). The study noted that toluene and other volatile organic compounds are found in a variety of household and industrial products, and thus have many potential point and diffuse sources in urban, and to a lesser extent rural, areas. Toluene may also come from natural sources, possibly including coal seams, but little literature exists on the topic. A third potential source of toluene in some wells is the well casing itself, since some wells, especially those intended for domestic or municipal water supply, had PVC casing held together by solvent cement (Don Jones, personal communication). It is conceivable that toluene leached into some samples from this product. Environmental concerns related to elevated concentrations of toluene in groundwater include problems with the central nervous system and respiratory or irritant effects (Health Canada, 2006). Xylenes were detected only in one groundwater sample (Gull Lake 309: 0.0006 mg/L) at a concentration below the acceptable value in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006). Only aesthetic objectives for toluene, ethylbenzene and xylene have been recorded in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006), as these compounds are volatile and are mainly of concern if inhaled.

4.1.6 *Phenols*

The results for phenol concentrations in forty groundwater samples are summarized in Table 6. Thirty two of the groundwater samples contained phenol concentrations above the detection limit. Groundwater from the Ministik Lake 2322E OBS 438 well contained the highest concentration of phenols at 0.057 mg/L, and water from Pine Lake contained the lowest detectable concentration of phenols at 0.007 mg/L. In 2006 Health Canada archived guidelines for various parameters. The guideline for phenols has been archived, because according to Health Canada (2006) it is no longer found in Canadian drinking water supplies at levels that could pose a risk to human health and because a more specific category, chlorinated phenols, makes the general phenol standard redundant. Anthropogenic sources of phenols include waste disposal and industrial sites, especially those related to wood treatment, as well as a variety of household chemicals. Coal represents a potential natural source for phenol as well as many other organic compounds (e.g. Schobert and Song, 2002). It is therefore possible that much of the phenol observed in this study could be natural since many wells in this study were in remote areas and were completed in coal-bearing aquifers. One of the blanks analyzed in this study showed a phenol concentration of 0.004 mg/L, suggesting that very low phenol concentrations must be evaluated critically, and that a re-evaluation of the sampling and analytical procedures used in this study is required before further conclusions can be drawn.

Table 5 Benzene, toluene, ethylbenzene and xylene concentrations in groundwater samples in Alberta, Canada

Field Site	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)
Cluny 85-1	n.d.	n.d.	n.d.	n.d.
Carseland	n.d.	n.d.	n.d.	n.d.
Irricana	n.d.	n.d.	n.d.	n.d.
Wheatland Rosebud	n.d.	n.d.	n.d.	n.d.
Hussar Well	n.d.	n.d.	n.d.	n.d.
Gull Lake 309	n.d.	0.0006	n.d.	0.0006
Warner 215	n.d.	n.d.	n.d.	n.d.
Warner 214	n.d.	n.d.	n.d.	n.d.
Water Well #1	n.d.	n.d.	n.d.	n.d.
Pine Lake 2688E	n.d.	n.d.	n.d.	n.d.
Botanical Gardens 2327 OBS 160	n.d.	0.0008	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	0.0027	n.d.	n.d.
Water Well #2	n.d.	n.d.	n.d.	n.d.
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	0.003	n.d.	n.d.
Dickson Dam 308	n.d.	0.085	n.d.	n.d.
Elnora #6 128	n.d.	0.008	n.d.	n.d.
Water Well #3	n.d.	n.d.	n.d.	n.d.
Donalda well	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	n.d.	0.0007	n.d.	n.d.
ALTA Public works #2	n.d.	n.d.	n.d.	n.d.
Halkirk Town well	n.d.	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	n.d.	n.d.
Handhills 1 OBS 124	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	0.0058	n.d.	n.d.
Olds OBS 227	n.d.	0.0006	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	0.0031	n.d.	n.d.
Pine Lake 398	n.d.	0.0006	n.d.	n.d.
Meadowglen 299	n.d.	0.01	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.	n.d.
Galahad 292	n.d.	0.00071	n.d.	n.d.
Airdrie 456	n.d.	0.00216	n.d.	n.d.
Metiskow 88-2	n.d.	0.0018	n.d.	n.d.
Ferintosh OBS 147	n.d.	0.00068	n.d.	n.d.
Hardisty 1869	n.d.	0.0014	n.d.	n.d.
Metiskow 88-1	n.d.	0.00472	n.d.	n.d.
Cluny 5				
Cluny 6				
Test well 4				
Test well 5				

n.d. Not Detected
- Sample Not Available

Values above AO guidelines

Table 5 Benzene, toluene, ethylbenzene and xylene concentrations in groundwater samples in Alberta, Canada

Field Site	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)
Cluny 85-1	n.d.	n.d.	n.d.	n.d.
Carseland	n.d.	n.d.	n.d.	n.d.
Irricana	n.d.	n.d.	n.d.	n.d.
Wheatland Rosebud	n.d.	n.d.	n.d.	n.d.
Hussar Well	n.d.	n.d.	n.d.	n.d.
Gull Lake 309	n.d.	0.0006	n.d.	0.0006
Warner 215	n.d.	n.d.	n.d.	n.d.
Warner 214	n.d.	n.d.	n.d.	n.d.
Water Well #1	n.d.	n.d.	n.d.	n.d.
Pine Lake 2688E	n.d.	n.d.	n.d.	n.d.
Botanical Gardens 2327 OBS 160	n.d.	0.0008	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	0.0027	n.d.	n.d.
Water Well #2	n.d.	n.d.	n.d.	n.d.
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	0.003	n.d.	n.d.
Dickson Dam 308	n.d.	[redacted]	n.d.	n.d.
Elnora #6 128	n.d.	0.008	n.d.	n.d.
Water Well #3	n.d.	n.d.	n.d.	n.d.
Donalda well	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	n.d.	0.0007	n.d.	n.d.
ALTA Public works #2	n.d.	n.d.	n.d.	n.d.
Halkirk Town well	n.d.	n.d.	n.d.	n.d.
Stettler 60-4 OBS 137	n.d.	n.d.	n.d.	n.d.
Handhills 1 OBS 124	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	0.0058	n.d.	n.d.
Olds OBS 227	n.d.	0.0006	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	0.0031	n.d.	n.d.
Pine Lake 398	n.d.	0.0006	n.d.	n.d.
Meadowglen 299	n.d.	0.01	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.	n.d.
Galahad 292	n.d.	0.00071	n.d.	n.d.
Airdrie 456	n.d.	0.00216	n.d.	n.d.
Metiskow 88-2	n.d.	0.0018	n.d.	n.d.
Ferintosh OBS 147	n.d.	0.00068	n.d.	n.d.
Hardisty 1869	n.d.	0.0014	n.d.	n.d.
Metiskow 88-1	n.d.	0.00472	n.d.	n.d.
Cluny 5	-	-	-	-
Cluny 6	-	-	-	-
Test well 4	-	-	-	-
Test well 5	-	-	-	-

n.d. Not Detected
\- Sample Not Available

[redacted] Values above AO guidelines

4.1.7 Volatile Organic Acids (as Acetic)

Results for volatile organic acids (VOA) for thirty-five groundwater samples are summarized in Table 6. Of the wells that were characterized by concentrations of organic acids above the detection limit, groundwater from Handhills 1 OBS 124 contained the lowest concentration of VOA's at 7 mg/L and groundwater from the Olds OBS 227 well contained the highest concentration of VOA's at 190 mg/L. The concentration of VOA's in groundwater may be related to bacterial sulphate reduction. High VOA concentrations are usually found in groundwater with high concentrations of sulphate. Samples containing low VOA are often associated with low sulphate concentrations and may contain methane in the water (Routh et al., 2001). The samples from this study showed no correlation between VOA concentrations and sulphate concentrations, and there was no correlation between VOA concentration and methane content. There was considerable variation between the results of triplicate samples and the blank samples tested positive for VOA, indicating that the VOA method used in this study was not very reliable. Recent analysis of a different set of sampling equipment blanks by the Alberta Research Council (ARC) indicated that the sampling method likely did not bias the results, since field methods have not changed since this study (Don Jones, personal communication). A re-evaluation of the analytical techniques used in this study is therefore required before further conclusions can be drawn.

4.1.8 Polycyclic Aromatic Hydrocarbons (PAH)

Seventeen different polyaromatic hydrocarbon compounds were analyzed, and results for thirty groundwater samples are summarized in Table 7. According to Health Canada (2006), benzo[a]pyrene is the only PAH that has a MAC (0.01 µg/L). The guidelines for all other PAHs have been archived, as Health Canada (2006) has proposed that these PAHs are not found in Canadian drinking water supplies, and thus do not pose a threat to human health, or that they are covered by other categories in the their Drinking Water Quality Guidelines. The majority of the PAHs in the groundwater were below the detection limit. The groundwater samples from Botanical Gardens, Water Well #2, Elnora #6 128, Water Well #3, Buffalo Lake OBS 4004C, ALTA Public Works #2, and Halkirk Town well contained elevated PAH concentrations of up to 0.3 µg/L specifically in fluoranthene, pyrene, benzo(a)anthracene, benzo(b)fluoranthene, and benzo(a)pyrene.

Table 6 Volatile organic acids (as acetic acid) and phenols in groundwater samples in Alberta, Canada

Field Site	Phenols (mg/L)	Volatile Organic Acids (as Acetic) (mg/L)
Cluny 85-1	0.05	95
Carseland	0.021	140
Irricana	0.018	78
Wheatland Rosebud	0.026	56
Hussar Well	0.014	62
Gull Lake 309	n.d.	64
Warner 215	0.020	110
Warner 214	0.01	94
Water Well #1	0.03	48
Pine Lake 2688E	0.007	48
Botanical Gardens 2327 OBS 160	0.024	-
Ministik Lake 2322E OBS 438	0.057	-
Edson Well	0.023	n.d.
Drayton Valley 368	0.026	8
Water Well #2	0.035	-
Ponoka 60-2 144	0.023	-
Warburg #2187E OBS 316	0.023	11
Dickson Dam 308	0.021	8
Elnora #6 128	0.014	n.d.
Water Well #3	0.029	-
Donalda well	0.026	8
Buffalo Lake OBS 4004C	0.014	n.d.
ALTA Public works #2	0.021	9
Halkirk Town well	0.016	13
Stettler 60-4 OBS 137	0.017	n.d.
Handhills 1 OBS 124	0.029	7
Handhills 2 OBS 125	0.013	12
Olds OBS 227	0.014	190
Olds OBS 126	0.019	n.d.
Okotoks 2378E217	0.024	n.d.
Pine Lake 398	0.015	9
Meadowglen 299	0.015	n.d.
Three Hills RCA 144	0.014	10
Wetaskiwin	n.d.	17
Galahad 292	n.d.	11
Airdrie 456	n.d.	11
Metiskow 88-2	n.d.	20
Ferintosh OBS 147	n.d.	11
Hardisty 1869	n.d.	15
Metiskow 88-1	n.d.	22
Cluny 5	-	-
Cluny 6	-	-
Test well 4	-	-
Test well 5		

4.1.9 Sulphide Concentrations

Sulphide concentrations in the groundwater samples are listed in Table 8. Ten groundwater samples had sulphide concentrations higher than 0.1 mg/L. The Warner 215 well contained the highest concentration of sulphides at 8.5 mg/L. The occurrence of dissolved sulphide is a potential indicator for bacterial (dissimilatory) sulphate reduction in the aquifer. Samples from several wells (Warburg # 2187E OBS 316, Harkirk Town Well, Hand Hills 1 OBS 124, and Mestikow 88-1) exhibited sulphate concentrations at or below 1 mg/L, while not containing detectable sulphide. Free gas samples from these wells also lacked detectable hydrogen sulphide (unpublished data). These results suggest that sulphide may have reacted with other ions, such as ferrous iron, and precipitated out of solution. It is also possible that some wells had low sulphate concentrations to begin with and were not strongly affected by bacterial sulphate reduction. It is also notable that there was large variation between replicate samples of sulphide (Test Well 4: 1.3 mg/L vs. Test Well 5: 0.3 mg/L), and that the blank samples showed concentrations of 0.1 mg/L, suggesting some problems with the sampling procedures or analytical method.

4.1.10 Silica

Silica concentrations for the forty groundwater samples are listed in Table 9. Silica concentrations varied between 1.6 mg/L in groundwater from the Dickson Dam 308 well and 11.9 mg/L in groundwater from the Halkirk Town well. Silica concentration is an important input parameter for geochemical modeling.

Table 7 Polycyclic aromatic hydrocarbons in groundwater samples from Alberta, Canada

Field Site	Naphthalene µg/L	Acenaphthylene µg/L	Acenaphthene µg/L	Fluorene µg/L	Phenanthrene µg/L
Cluny 85-1	-	-	-	-	-
Carseland	-	-	-	-	-
Irricana	-	-	-	-	-
Wheatland Rosebud	-	-	-	-	-
Hussar Well	-	-	-	-	-
Gull Lake 309	-	-	-	-	-
Warner 215	-	-	-	-	-
Warner 214	-	-	-	-	-
Water Well #1	-	-	-	-	-
Pine Lake 2688E	-	-	-	-	-
Botanical Gardens 2327 OBS 160	n.d.	n.d.	n.d.	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	n.d.	n.d.	n.d.
Water Well #2	n.d.	n.d.	n.d.	n.d.	n.d.
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	n.d.	n.d.	n.d.	n.d.
Dickson Dam 308	n.d.	n.d.	n.d.	n.d.	n.d.
Elnora #6 128	n.d.	n.d.	n.d.	n.d.	0.05
Water Well #3	0.04	0.02	0.02	0.03	0.16
Donalda well	n.d.	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	0.05	0.01	0.02	0.02	0.13
ALTA Public works #2	0.01	0.01	0.02	0.02	0.12
Halkirk Town well	n.d.	n.d.	n.d.	n.d.	0.05
Stettler 60-4 OBS 137	0.07	n.d.	n.d.	0.01	0.01
Handhills 1 OBS 124	n.d.	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 126	0.02	n.d.	n.d.	0.01	0.02
Okotoks 2378E217	0.02	n.d.	n.d.	n.d.	0.01
Pine Lake 398	n.d.	n.d.	n.d.	n.d.	n.d.
Meadowglen 299	n.d.	n.d.	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.	n.d.	n.d.
Galahad 292	n.d.	n.d.	n.d.	n.d.	n.d.
Airdrie 456	n.d.	n.d.	n.d.	n.d.	n.d.
Metiskow 88-2	n.d.	n.d.	n.d.	n.d.	n.d.
Ferintosh OBS 147	n.d.	n.d.	n.d.	n.d.	n.d.
Hardisty 1869	n.d.	n.d.	n.d.	n.d.	n.d.
Metiskow 88-1	n.d.	n.d.	n.d.	n.d.	n.d.

Table 7 (Cont'd...)

Field Site	Naphthalene µg/L	Acenaphthylene µg/L	Acenaphthene µg/L	Fluorene µg/L	Phenanthrene µg/L
Cluny 5	-	-	-	-	-
Cluny 6	-	-	-	-	-
Test well 4	-	-	-	-	-
Test well 5	-	-	-	-	-

n.d. Not Detected

\- Sample Not Available

Values above MAC guidelines

Values above AO guidelines

Table 7 (Cont'd...)

Field Site	Anthracene µg/L	Acridine µg/L	Fluoranthene µg/L	Pyrene µg/L	Benzo(a)anthracene µg/L
Cluny 85-1	-	-	-	-	-
Carseland	-	-	-	-	-
Irricana	-	-	-	-	-
Wheatland Rosebud	-	-	-	-	-
Hussar Well	-	-	-	-	-
Gull Lake 309	-	-	-	-	-
Warner 215	-	-	-	-	-
Warner 214	-	-	-	-	-
Water Well #1	-	-	-	-	-
Pine Lake 2688E	-	-	-	-	-
Botanical Gardens 2327 OBS 160	n.d.	n.d.	n.d.	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	n.d.	n.d.	n.d.
Water Well #2	n.d.	n.d.	0.07	0.08	0.03
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	n.d.	n.d.	n.d.	n.d.
Dickson Dam 308	n.d.	n.d.	n.d.	n.d.	n.d.
Elnora #6 128	n.d.	n.d.	0.11	0.1	0.05
Water Well #3	0.02	n.d.	0.31	0.26	0.15
Donalda well	n.d.	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	0.01	n.d.	0.23	0.19	0.11
ALTA Public works #2	0.01	n.d.	0.25	0.21	0.11
Halkirk Town well	n.d.	n.d.	0.11	0.1	0.05
Stettler 60-4 OBS 137	n.d.	n.d.	n.d.	n.d.	n.d.
Handhills 1 OBS 124	n.d.	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	n.d.	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.	n.d.	n.d.	n.d.
Pine Lake 398	n.d.	n.d.	n.d.	n.d.	n.d.
Meadowglen 299	n.d.	n.d.	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.	n.d.	n.d.
Galahad 292	n.d.	n.d.	0.02	n.d.	0.01
Airdrie 456	n.d.	n.d.	n.d.	n.d.	n.d.
Metiskow 88-2	n.d.	n.d.	n.d.	n.d.	n.d.
Ferintosh OBS 147	n.d.	n.d.	n.d.	n.d.	n.d.
Hardisty 1869	n.d.	n.d.	n.d.	n.d.	n.d.
Metiskow 88-1	n.d.	n.d.	n.d.	n.d.	n.d.

Table 7 (Cont'd...)

Field Site	Anthracene µg/L	Acridine µg/L	Fluoranthene µg/L	Pyrene µg/L	Benzo(a)anthracene µg/L
Cluny 5	-	-	-	-	-
Cluny 6	-	-	-	-	-
Test well 4	-	-	-	-	-
Test well 5	-	-	-	-	-

n.d. Not Detected

\- Sample Not Available

Values above MAC guidelines

Values above AO guidelines

Table 7 (Cont'd...)

Field Site	Chrysene µg/L	Benzo(b)fluoranthene µg/L	Benzo(k)fluoranthene µg/L	Benzo(a)pyrene µg/L
Cluny 85-1	-	-	-	-
Carseland	-	-	-	-
Irricana	-	-	-	-
Wheatland Rosebud	-	-	-	-
Hussar Well	-	-	-	-
Gull Lake 309	-	-	-	-
Warner 215	-	-	-	-
Warner 214	-	-	-	-
Water Well #1	-	-	-	-
Pine Lake 2688E	-	-	-	-
Botanical Gardens 2327 OBS 160	n.d.	n.d.	n.d.	0.02
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	n.d.	n.d.
Water Well #2	0.04	0.03	0.02	0.02
Ponoka 60-2 144	n.d.	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	n.d.	n.d.	n.d.
Dickson Dam 308	0.01	n.d.	n.d.	0.01
Elnora #6 128	0.07	0.07	0.04	0.06
Water Well #3	0.21	0.22	0.12	0.18
Donalda well	n.d.	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	0.15	0.15	0.08	0.12
ALTA Public works #2	0.16	0.16	0.08	0.12
Halkirk Town well	0.07	0.07	0.04	0.06
Stettler 60-4 OBS 137	n.d.	n.d.	n.d.	n.d.
Handhills 1 OBS 124	n.d.	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.	n.d.	n.d.
Pine Lake 398	n.d.	n.d.	n.d.	n.d.
Meadowglen 299	n.d.	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.	n.d.
Galahad 292	0.01	0.01	0.01	0.01
Airdrie 456	n.d.	n.d.	n.d.	n.d.
Metiskow 88-2	n.d.	n.d.	n.d.	n.d.
Ferintosh OBS 147	n.d.	n.d.	n.d.	n.d.
Hardisty 1869	n.d.	n.d.	n.d.	0.01
Metiskow 88-1	n.d.	n.d.	n.d.	n.d.

Table 7 (Cont'd...)

Field Site	Chrysene µg/L	Benzo(b)fluoranthene µg/L	Benzo(k)fluoranthene µg/L	Benzo(a)pyrene µg/L
Cluny 5	-	-	-	-
Cluny 6	-	-	-	-
Test well 4	-	-	-	-
Test well 5	-	-	-	-

n.d. Not Detected

\- Sample Not Available

Values above MAC guidelines

Values above AO guidelines

Table 7 (Cont'd...)

Field Site	Indeno(1,2,3-c,d) pyrene µg/L	Dibenzo(a,h)anthracene µg/L	Benzo(g,h,i)perylene µg/L
Cluny 85-1	-	-	-
Carseland	-	-	-
Irricana	-	-	-
Wheatland Rosebud	-	-	-
Hussar Well	-	-	-
Gull Lake 309	-	-	-
Warner 215	-	-	-
Warner 214	-	-	-
Water Well #1	-	-	-
Pine Lake 2688E	-	-	-
Botanical Gardens 2327 OBS 160	n.d.	n.d.	n.d.
Ministik Lake 2322E OBS 438	n.d.	n.d.	n.d.
Edson Well	n.d.	n.d.	n.d.
Drayton Valley 368	n.d.	n.d.	n.d.
Water Well #2	0.02	n.d.	0.02
Ponoka 60-2 144	n.d.	n.d.	n.d.
Warburg #2187E OBS 316	n.d.	n.d.	n.d.
Dickson Dam 308	n.d.	n.d.	n.d.
Elnora #6 128	0.04	0.02	0.04
Water Well #3	0.14	0.03	0.14
Donalda well	n.d.	n.d.	n.d.
Buffalo Lake OBS 4004C	0.09	0.02	0.08
ALTA Public works #2	0.1	0.02	0.09
Halkirk Town well	0.04	0.02	0.04
Stettler 60-4 OBS 137	n.d.	n.d.	n.d.
Handhills 1 OBS 124	n.d.	n.d.	n.d.
Handhills 2 OBS 125	n.d.	n.d.	n.d.
Olds OBS 227	n.d.	n.d.	n.d.
Olds OBS 126	n.d.	n.d.	n.d.
Okotoks 2378E217	n.d.	n.d.	n.d.
Pine Lake 398	n.d.	n.d.	n.d.
Meadowglen 299	n.d.	n.d.	n.d.
Three Hills RCA 144	n.d.	n.d.	n.d.
Wetaskiwin	n.d.	n.d.	n.d.
Galahad 292	0.01	n.d.	0.01
Airdrie 456	n.d.	n.d.	n.d.
Metiskow 88-2	n.d.	n.d.	n.d.
Ferintosh OBS 147	n.d.	n.d.	n.d.
Hardisty 1869	n.d.	n.d.	n.d.
Metiskow 88-1	n.d.	n.d.	n.d.

Table 7 (Cont'd...)

Field Site	Indeno(1,2,3-c,d) pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene
	µg/L	µg/L	µg/L
Cluny 5	-	-	-
Cluny 6	-	-	-
Test well 4	-	-	-
Test well 5	-	-	-

n.d. Not Detected

\- Sample Not Available

Values above MAC guidelines

Values above AO guidelines

Table 8 Sulphide concentrations for groundwater samples from Alberta, Canada

Field Site	Sulphide Concentration (mg/L)
Cluny 85-1	0.0
Carseland	0.1
Irricana	0.1
Wheatland Rosebud	0.1
Hussar Well	0.1
Gull Lake 309	0.1
Warner 215	8.5
Warner 214	0.7
Water Well #1	0.4
Pine Lake 2688E	0.1
Botanical Gardens 2327 OBS 160	0.0
Ministik Lake 2322E OBS 438	0.9
Edson Well	0.0
Drayton Valley 368	0.0
Water WellL #2	0.1
Ponoka 60-2 144	0.0
Warburg #2187E OBS 316	0.0
Dickson Dam 308	0.4
Elnora #6 128	0.4
Water Well #3	3.0
Donalda well	0.0
Buffalo Lake OBS 4004C	0.0
ALTA Public works #2	0.0
Halkirk Town well	0.0
Stettler 60-4 OBS 137	0.1
Handhills 1 OBS 124	0.0
Handhills 2 OBS 125	0.0
Olds OBS 227	0.0
Olds OBS 126	0.0
Okotoks 2378E217	0.0
Pine Lake 398	0.1
Meadowglen 299	0.0
Three Hills RCA 144	0.0
Wetaskiwin	0.0
Galahad 292	0.3
Airdrie 456	0.6
Metiskow 88-2	0.0
Ferintosh OBS 147	0.1
Hardisty 1869	0.1
Metiskow 88-1	0.0
Cluny 5	0.1
Cluny 6	0.1
Test well 4	1.3
Test well 5	0.3

Table 9 Silica concentrations for groundwater samples from Alberta, Canada

Field Site	Si
	µg/L
Cluny 85-1	3424
Carseland	3187
Irricana	3026
Wheatland Rosebud	3529
Hussar Well	4377
Gull Lake 309	5906
Warner 215	3360
Warner 214	4451
Water Well #1	3115
Pine Lake 2688E	3490
Botanical Gardens 2327 OBS 160	3618
Ministik Lake 2322E OBS 438	9443
Edson Well	3025
Drayton Valley 368	4333
Water Well #2	3808
Ponoka 60-2 144	5539
Warburg #2187E OBS 316	3197
Dickson Dam 308	1620
Elnora #6 128	4126
Water Well #3	3417
Donalda well	8814
Buffalo Lake OBS 4004C	6697
ALTA Public works #2	8970
Halkirk Town well	11925
Stettler 60-4 OBS 137	7564
Handhills 1 OBS 124	4162
Handhills 2 OBS 125	8038
Olds OBS 227	3778
Olds OBS 126	3455
Okotoks 2378E217	3041
Pine Lake 398	2989
Meadowglen 299	4075
Three Hills RCA 144	3071
Wetaskiwin	3780
Galahad 292	8722
Airdrie 456	3661
Metiskow 88-2	3535
Ferintosh OBS 147	9674
Hardisty 1869	3621
Metiskow 88-1	3722
Cluny 5	n.a.
Cluny 6	n.a.
Test well 4	n.a.
Test well 5	n.a.

4.1.11 Stable Isotopes

4.1.11.1 Oxygen and Hydrogen

Oxygen and hydrogen isotope ratios of the groundwater samples are summarized in Table 10. The $\delta^{18}O$ values for the groundwater samples ranged from -15.1 to -21.4 ‰ and the δD values varied from -126.9 to -170.7 ‰. These isotopic compositions are similar to that of precipitation in southern Alberta (Peng et al., 2004) and hence indicate local recharge. Only the groundwater obtained from the Warner 214 well had $\delta^{18}O$ (-8.7 ‰) and δD values (-96.3 ‰) that were significantly higher than that of local recharge water, indicating the influence of formation waters. High TDS values (4,300 mg/L) and methane concentrations also suggest that contact with formation waters has influenced the groundwater from this sample.

Figure 5 displays $\delta^{18}O_{water}$ versus δD_{water} values for the groundwater samples compared to the so-called Local Meteoric Water Line for Calgary (LMWL):

$$\delta D_{water} = 7.68\ \delta^{18}O_{water} - 0.21\ (R^2 = 0.96)\ \text{(Peng et al. 2004)}$$

The isotopic composition of all groundwater samples plots below the LMWL and linear regression exhibits a slope of 6.0 compared to the slope of the LMWL (7.7). Enrichment of ^{2}H and ^{18}O in some samples and a slope lower than that of the LMWL suggests that the groundwater has undergone some evaporation during recharge (Faure, 1986).

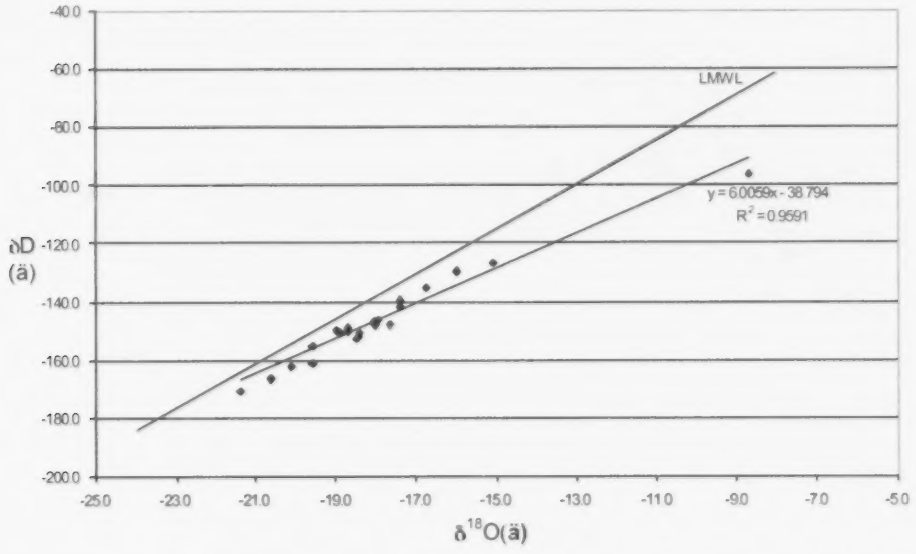

Figure 5: Plot of $\delta^{18}O_{H2O}$ vs. δD_{H2O} from water in samples from Alberta, Canada and its relation to the Local Meteoric Water Line (LMWL) (Peng et al., 2004)

4.1.11.2 *Sulphate*

The groundwater samples were analyzed for the isotopic composition of sulphate, and the results are summarized in Table 10. The $\delta^{34}S_{sulphate}$ values in these groundwater samples ranged from -26.6 ‰ to +34.3 ‰ and the $\delta^{18}O_{sulphate}$ values ranged from -13.3 ‰ to +7.7 ‰. The negative $\delta^{34}S$ and $\delta^{18}O$ values of many sulphate samples as well as high sulphate concentrations (>40 mg/L) indicate that pyrite oxidation is a major process of sulphate formation. Elevated $\delta^{34}S$ and $\delta^{18}O$ values together with low sulphate concentrations indicated the occurrence of bacterial (dissimilatory) sulphate reduction in the aquifers.

4.1.11.3 *Carbon*

The isotope ratios of dissolved inorganic carbon (DIC) in the groundwater samples are summarized in Table 10. The $\delta^{13}C_{DIC}$ values in the groundwater ranged from -20.0 ‰ to +6.5‰, with one sample from the Warner 214 well having a much higher value (+21.2 ‰). The most negative $\delta^{13}C$ values indicate that organic C is the source for DIC. Intermediate $\delta^{13}C$ values are likely associated with carbonate dissolution. The positive $\delta^{13}C$ values provide evidence for methanogenesis.

4.1.11.4 *Nitrate*

Only three groundwater samples contained adequate nitrate concentrations for isotope analysis (Table 10). Nitrate in groundwater from Handhills 2 OBS 126 (0.86 mg/L nitrate) and Okotoks 2378 E217 (3.36 mg/L nitrate) had $\delta^{15}N$ values of 7.4 and 9.7 ‰ and negative $\delta^{18}O$ values indicating an agricultural or waste water source of the nitrate. The isotopic composition of nitrate in groundwater from Meadowglen 299 (0.34 mg/L nitrate) with a $\delta^{15}N$ value of -10.1 ‰ was rather unusual and may indicate the influence of an anthropogenic nitrate source.

4.1.12 *Gas Composition*

4.1.12.1 *Dissolved Gas*

Twenty-eight groundwater samples were analyzed for their concentration of dissolved gas (Table 11). Only 9 samples contained enough methane for isotope analysis and the $\delta^{13}C_{CH4}$ values ranged from -52.5 ‰ to -83.3 ‰. Twenty-seven samples contained enough CO_2 for isotope analysis and the $\delta^{13}C_{CO2}$ values ranged from -28.1 ‰ to -1.4 ‰.

4.1.12.2 *Free Gas*

Thirty-four samples were analyzed for their gas composition (Table 12). The average methane concentration was 288,928 ppmv (28.9 %v). Free gas from the Water Well #2 well contained the highest methane concentration at 995,000 ppmv (99.5 %v) and free gas from the Okotoks 2378E217 well contained the lowest methane content at 0.293 ppmv. Ethane concentrations ranged from 1 ppmv to 3650 ppmv, and carbon dioxide concentrations ranged from 228 ppmv to 54100 ppmv.

The relative proportion of methane vs. higher alkanes (e.g. ethane, propane, butane etc.) in gas samples can give important clues to the origin of the gas, since thermogenic gas generally has a larger proportion of higher alkanes relative to methane than biogenic gas (e.g. Schoell, 1980). For example, it is often assumed that natural gas with a ratio of methane to higher alkanes greater than 1000:1 is biogenic (Taylor et al. 2000). Exceptions are possible, however, since some biogenic gases have been reported with ratios of methane to ethane as low as 200:1 (Schoell 1980). The ratio of methane to ethane in the free gas sampled in this study was greater

than 1000:1 in all but six wells (Irricana, Warner 214, Pine Lake 2688E, Water Well #3, Donalda Well, and Halkirk Town well). Of these, the sample from Halkirk town well had the lowest methane to ethane ratio (263:1).

With respect to the apparently high concentrations of methane in some wells, it should be noted that a high concentration in the free gas phase might not indicate that the sampled groundwater is associated with a large amount of methane. The amount of pumping required to generate a given volume of gas varied greatly from well to well in this study (Don Jones, personal communication). The amount of gas produced per litre of water pumped is also somewhat dependent on the design of the gas sampler and how it is connected to the well. For example, in this study there was a gate valve on the hose from the wellhead to the gas sampler. This gate valve was constricted in wells that were not producing free gas in the sampler under normal conditions, creating a sudden pressure drop in the hose that caused gas to come out of solution (Don Jones, personal communication).

Thirty-one free gas samples were analyzed for their $\delta^{13}C_{CH4}$ and $\delta^{13}C_{CO2}$ values and nineteen samples had enough ethane for $\delta^{13}C$ analyses (Table 12). For samples with methane contents of >0.5%, the $\delta^{13}C_{CH4}$ values ranged from -60.4 ‰ to -83.9 ‰. For comparison, the $\delta^{13}C_{CH4}$ values associated with water produced from CBM wells completed in the Horseshoe Canyon/Belly River Group in Alberta ranged from -52 ‰ to -60 ‰ in 39 of the 45 wells tested (Mayer and Klassen, 2007). The fact that all of the free gas samples with significant concentrations of methane exhibited $\delta^{13}C_{CH4}$ values of less than -60 ‰ in conjunction with the high ratios of methane to ethane in these samples provides strong evidence that the methane is predominantly of biogenic origin. $\delta^{13}C_{CO2}$ values ranged from -3.3 ‰ to -27.4 ‰. The $\delta^{13}C$ values of ethane ranged from -44.0 ‰ to -65.9 ‰, with one exception: Warner 215 having a $\delta^{13}C$ value of ethane of -36.1 ‰.

Table 10 Stable isotope ratios of oxygen and hydrogen in water, sulphur and oxygen of sulphate, carbon isotope ratios of dissolved inorganic carbon (DIC), and nitrogen in nitrate

Field Site	$\delta^{18}O_{H2O}$	δD_{H2O}	$\delta^{34}S_{sulphate}$	$\delta^{18}O_{sulphate}$	$\delta^{13}C_{DIC}$	$\delta^{15}N_{nitrate}$	$\delta^{18}O_{nitrate}$
	(‰)	(‰)	(‰)	(‰)	(‰)	(‰)	(‰)
Cluny 85-1	-18.4	-150.7	14.0	-	-6.3	n.d.	n.d.
Carseland	-21.4	-170.7	-3.5	0.0	-15.8	n.d.	n.d.
Irricana	-20.6	-166.2	4.1	2.2	-16.3	n.d.	n.d.
Wheatland Rosebud	-19.0	-149.4	5.6	1.5	-12.9	n.d.	n.d.
Hussar Well	-19.6	-161.0	2.1	-2.1	-6.1	n.d.	n.d.
Gull Lake 309	-15.1	-126.9	-3.7	-	4.3	n.d.	n.d.
Warner 215	-18.7	-149.7	5.5	1.8	-19.1	n.d.	n.d.
Warner 214	-8.7	-96.3	-	-	21.2	n.d.	n.d.
Water Well #1	-16.8	-135.4	-16.1	-8.0	-4.5	n.d.	n.d.
Pine Lake 2688E	-18.4	-152.0	-2.1	-2.5	-12.6	n.d.	n.d.
Botanical Gardens 2327 OBS 160	-17.4	-141.6	-3.7	-12.4	-3.7	n.d.	n.d.
Ministik Lake 2322E OBS 438	-18.0	-147.6	34.3	6.8	-20.0	n.d.	n.d.
Edson Well	-19.6	-155.4	20.8	3.5	-11.6	n.d.	n.d.
Drayton Valley 368	-17.9	-146.0	-11.9	-5.1	-14.8	n.d.	n.d.
Water Well #2	-16.0	-129.4	-1.3	n.d.	6.5	n.d.	n.d.
Ponoka 60-2 144	-18.5	-152.3	-6.9	-0.6	-14.5	n.d.	n.d.
Warburg #2187E OBS 316	-17.4	-139.4	-4.3	n.d.	-8.1	n.d.	n.d.
Dickson Dam 308	-18.7	-148.8	14.5	-0.1	-11.5	n.d.	n.d.
Elnora #6 128	-18.9	-149.7	-5.0	-9.6	-10.8	n.d.	n.d.
Water Well #3	-20.1	-161.8	0.4	0.3	-19.4	n.d.	n.d.
Donalda well	-18.9	-151.1	-7.4	-0.3	-15.7	n.d.	n.d.
Buffalo Lake OBS 4004C	-19.0	-155.1	-10.3	-2.0	-18.4	n.d.	n.d.
ALTA Public works #2	-18.1	-143.5	-0.7	1.0	-13.1	n.d.	n.d.
Halkirk Town well	-16.4	-131.7	-3.0	n.d.	4.7	n.d.	n.d.
Stettler 60-4 OBS 137	-20.3	-158.7	-5.3	-10.3	-13.7	n.d.	n.d.
Handhills 1 OBS 124	-19.5	-150.4	n.d.	n.d.	-1.7	n.d.	n.d.
Handhills 2 OBS 125	-18.3	-142.9	0.7	-6.8	-10.7	7.4	-8.4
Olds OBS 227	-20.3	-158.2	-10.7	-7.0	-9.7	n.d.	n.d.
Olds OBS 126	-20.2	-161.0	-10.7	-7.0	-9.6	n.d.	n.d.
Okotoks 2378E217	-18.3	-143.4	-12.1	-8.6	-11.8	9.7	-4.5
Pine Lake 398	-17.7	-140.7	0.6	2.5	-8.5	n.d.	n.d.
Meadowglen 299	-18.9	-146.6	-26.6	-13.3	-9.9	-10.1	-13.2
Three Hills RCA 144	-18.6	-145.3	3.7	1.2	-14.6	n.d.	n.d.
Wetaskiwin	-20.1	-161.2	-9.3	-1.4	-12.3	n.d.	n.d.
Galahad 292	-17.7	-144.8	-8.6	-2.8	-14.6	n.d.	n.d.
Airdrie 456	-17.3	-136.5	0.1	0.6	-15.7	n.d.	n.d.
Metiskow 88-2	-19.6	-152.5	-6.5	-3.2	-10.4	n.d.	n.d.
Ferintosh OBS 147	-18.4	-141.8	-6.7	-8.4	-13.3	n.d.	n.d.
Hardisty 1869	-17.9	-141.1	16.6	7.7	-9.4	n.d.	n.d.
Metiskow 88-1	-16.5	-124.5	n.d.	n.d.	-1.5	n.d.	n.d.

Table 10 (Cont'd...)

Field Site	$\delta^{18}O_{H2O}$ (‰)	δD_{H2O} (‰)	$\delta^{34}S_{sulphate}$ (‰)	$\delta^{18}O_{sulphate}$ (‰)	$\delta^{13}C_{DIC}$ (‰)	$\delta^{15}N_{nitrate}$ (‰)	$\delta^{18}O_{nitrate}$ (‰)
Cluny 5	-17.7	-148.1	-	-	-	n.d.	n.d.
Cluny 6	-18.1	-147.4	4.8	-	-	n.d.	n.d.
Test well 4	-18.1	-146.6	33.9	6.4	-19.7	n.d.	n.d.
Test well 5	-18.0	-147.5	34.1	7.6	-19.8	n.d.	n.d.

n.d. Not Detected

\- Sample Not Available

Table 11 Stable isotopes of carbon in methane, ethane and carbon dioxide in dissolved gas

Field Site	Dissolved Gas					
	$\delta^{13}C_{CH4}$	$[CH_4]$	$\delta^{13}C_{C2}$	$[C_2H_6]$	$\delta^{13}C_{Co2}$	$[CO_2]$
	(‰)	µg/L	(‰)	µg/L	(‰)	µg/L
Cluny 85-1	-	9980	-	1.28	-	7.38
Carseland	-	2	-	n.d.	-	14.20
Irricana	-	106	-	0.69	-	4.89
Wheatland Rosebud	-	5830	-	2.89	-	5.08
Hussar Well	-	12	-	n.d.	-	29.60
Gull Lake 309	-	13100	-	6.61	-	8.94
Warner 215	-	12867	-	22.03	-	17.07
Warner 214	-	48100	-	204.00	-	45.50
Water Well #1	-	21800	-	17.50	-	9.68
Pine Lake 2688E	-	10	-	n.d.	-	10.60
Botanical Gardens 2327 OBS 160	-	25600	-	20.20	-	2.86
Ministik Lake 2322E OBS 438	-	8010	-	3.93	-	12.20
Edson Well	-69.6	8600	-	1.42	-19.1	0.48
Drayton Valley 368	n.d.	15	-	0.05	-22.6	10.50
Water Well #2	-62.6	35900	-	68.80	-1.4	1.38
Ponoka 60-2 144	n.d.	662	-	0.01	-22.1	40.00
Warburg #2187E OBS 316	-58.1	41900	-	L0.01	-15.7	0.59
Dickson Dam 308	n.d.	1	-	n.d.	-18.7	0.57
Elnora #6 128	n.d.	11	-	n.d.	-20.1	15.90
Water Well #3	-71.6	7400	-	37.50	-28.1	2.52
Donalda well	n.d.	124	-	0.69	-23.7	10.80
Buffalo Lake OBS 4004C	n.d.	6	-	0.05	-25.3	74.50
ALTA Public works #2	n.d.	-	-	-	-19.8	-
Halkirk Town well	-69.8	-	-	-	-3.4	-
Stettler 60-4 OBS 137	n.d.	2	-	n.d.	-21.3	70.60
Handhills 1 OBS 124	-73.2	21000	-	15.30	-10.4	2.82
Handhills 2 OBS 125	n.d.	37	-	0.02	-19.6	13.00
Olds OBS 227	n.d.	3	-	n.d.	n.d.	17.30
Olds OBS 126	n.d.	4	-	n.d.	-17.9	15.90
Okotoks 2378E217	n.d.	0	-	n.d.	-20.1	13.10
Pine Lake 398	n.d.	48	-	n.d.	-17.7	0.60
Meadowglen 299	n.d.	0	-	n.d.	-18.6	2.05
Three Hills RCA 144	n.d.	28	-	n.d.	-23.1	6.98
Wetaskiwin	n.d.	-	-	-	-20.1	-
Galahad 292	n.d.	3	-	n.d.	-20.6	20.90
Airdrie 456	-83.3	7740	-	25.10	-23.7	2.91
Metiskow 88-2	n.d.	4	-	n.d.	-18.0	1.86
Ferintosh OBS 147	n.d.	7	-	n.d.	-19.9	81.20
Hardisty 1869	-52.5	1920	-	0.45	-18.2	0.56
Metiskow 88-1	-66.2	43200	-	15.00	-13.4	1.46

Table 11 (Cont'd...)

Field Site	Dissolved Gas					
	$\delta^{13}C_{CH4}$ (‰)	$[CH_4]$ µg/L	$\delta^{13}C_{C2}$ (‰)	$[C_2H_6]$ µg/L	$\delta^{13}C_{Co2}$ (‰)	$[CO_2]$ µg/L
Cluny 5	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-
Test well 4	n.d.	8000	-	3.56	n.d.	11.30
Test well 5	n.d.	8130	-	3.65	n.d.	14.90

n.d. Not Detected

\- Sample Not Available

Table 12 Stable isotopes of carbon in methane, ethane and carbon dioxide in free gas

Field Site	Free Gas						
	$\delta^{13}C_{CH4}$	$[CH_4]$	$\delta^{13}C_{C2}$	$[C_2H_6]$	$\delta^{13}C_{CO2}$	$[CO_2]$	δD_{CH4}
	(‰)	ppmv	(‰)	ppmv	(‰)	ppmv	(‰)
Cluny 85-1	-76.9	347500	-	6.01	-15.8	624	n.d.
Carseland	-21.7	58	-	n.d.	-15.8	4520	n.d.
Irricana	-48.7	951	-	1.56	-23.6	416	n.d.
Wheatland Rosebud	-69.7	204000	-	32.8	-22.9	2370	-296.0
Hussar Well	-43.8	90	-	n.d.	-14.2	20500	n.d.
Gull Lake 309	-66.9	910000	-50.2	345	-10.1	975	-277.3
Warner 215	-77.7	372000	-36.1	221	-27.3	2500	-295.9
Warner 214	-	948000	-	1890	-	19100	n.d.
Water Well #1	-81.6	592000	-55.7	174	-13.5	577	-295.5
Pine Lake 2688E	-58.6	487	-	0.608	-14.4	1000	-
Botanical Gardens 2327 OBS 160	-73.8	638000	-44.0	172.5	-12.8	1385	-304.3
Ministik Lake 2322E OBS 438	-81.3	348000	0.0	39.2	-27.3	7260	-305.0
Edson Well	-70.3	241000	0.0	13.3	-16.4	228	-281.9
Drayton Valley 368	-62.2	-	0.0	-	-18.5	-	-
Water Well #2	-60.4	995000	-49.5	673	-7.6	869	-283.4
Ponoka 60-2 144	-	-	-	-	-	-	-
Warburg #2187E OBS 316	-61.0	797000	-	n.d.	-15.3	281	-279.3
Dickson Dam 308	-	-	-	-	-	-	-
Elnora #6 128	-	-	-	-	-	-	-
Water Well #3	-71.4	215000	-48.0	324	-26.0	1700	-279.3
Donalda well	-71.6	1400	-	2.84	-22.4	6860	-235.3
Buffalo Lake OBS 4004C	-	-	-	-	-	-	-
ALTA Public works #2	-59.9	353	-	n.d.	-19.1	34000	-
Halkirk Town well	-70.8	960000	-55.1	3650	-3.3	24000	-309.5
Stettler 60-4 OBS 137	-56.1	42	-	n.d.	-20.4	36800	-
Handhills 1 OBS 124	-73.5	717000	-57.6	169	-11.3	1500	-316.9
Handhills 2 OBS 125	-69.6	8420	-	3.62	-19.1	7270	-336.2
Olds OBS 227	-60.7	130	-	n.d.	-18.2	7475	-112.5
Olds OBS 126	-55.3	109	na	n.d.	-18.2	8470	-80.9
Okotoks 2378E217	-	0	-	n.d.	-20.1	9640	-
Pine Lake 398	-	7975	-	n.d.	-	689	-
Meadowglen 299	-	119	-	n.d.	-	1900	-
Three Hills RCA 144	-	1230	-	n.d.	-	6370	-
Wetaskiwin	-42.8	1045	-	n.d.	-20.7	2305	n.d.
Galahad 292	-	-	-	-	-	-	-
Airdrie 456	-83.9	127000	-45.6	100	-24.5	1600	-247.6
Metiskow 88-2	-	-	-	-	-	-	-
Ferintosh OBS 147	-83.4	214	-	n.d.	-20.6	54100	-
Hardisty 1869	-75.4	167000	-	16.7	-16.6	365	-295.4
Metiskow 88-1	-71.6	918000	-65.9	111	-9.6	470	-260.8

Table 12 (Cont'd...)

Field Site	Free Gas						
	$\delta^{13}C_{CH4}$ (‰)	$[CH_4]$ ppmv	$\delta^{13}C_{C2}$ (‰)	$[C_2H_6]$ ppmv	$\delta^{13}C_{Co2}$ (‰)	$[CO_2]$ ppmv	δD_{CH4} (‰)
Cluny 5	-	-	-	-	-	-	-
Cluny 6	-	-	-	-	-	-	-
Test well 4	-80.7	-	-	-	-26.9	-	-307.9
Test well 5	-81.3	363000	-	39	-27.4	5990	-308.3

n.d. Not Detected

\- Sample Not Available

Table 13 Saturation indices for anhydrite, aragonite, calcite, dolomite, and gypsum in 40 groundwater samples from Alberta, Canada

Field Site	Anhydrite (SI)	Aragonite (SI)	Calcite (SI)	Dolomite (SI)	Gypsum (SI)
	$CaSO_4$	$CaCO_3$	$CaMg(CO_3)^2$	$CaSO_4$	$CaSO_4^{-2}(H_2O)$
Cluny 85-1	-	-1.536	-1.378	-3.750	
Carseland	-1.801	-0.563	-0.405	-1.130	-1.545
Irricana	-2.712	-1.623	-1.466	-3.691	-2.455
Wheatland Rosebud	-3.359	-2.310	-2.154	-5.133	-3.103
Hussar Well	-1.666	-0.264		-1.152	-1.410
Gull Lake 309	-5.021	-0.835	-0.679	-2.408	-4.764
Warner 215	-2.927	-1.548	-1.391	-3.253	-2.671
Warner 214	-5.220	-1.872	-1.716	-3.692	-4.965
Water Well #1	-3.678	-1.962	-1.805	-4.094	-3.421
Pine Lake 2688E	-3.025	-1.684	-1.525	-3.790	-2.769
Botanical Gardens 2327 OBS 160	-	-1.298	-1.141	-3.316	-
Ministik Lake 2322E OBS 438	-3.314	-1.994	-1.836	-4.606	-3.058
Edson Well	-4.439	-1.286	-1.127	-2.831	-4.182
Drayton Valley 368	-2.141	-1.845	-1.686	-3.767	-1.885
Water Well #2	-	-1.836	-1.678	-4.375	-
Ponoka 60-2 144	-1.625	-0.306		-0.725	-1.369
Warburg #2187E OBS 316	-5.429	-1.144	-0.987	-2.942	-5.173
Dickson Dam 308	-4.033	-0.647	-0.491	-1.381	-3.777
Elnora #6 128	-2.037	-0.398		-0.910	-1.781
Water Well #3	-4.407	-1.457	-1.300	-3.646	-4.150
Donalda well	-2.061	-2.028	-1.870	-4.608	-1.805
Buffalo Lake OBS 4004C	-0.988		0.367		-0.731
ALTA Public works #2	-2.244	-0.480	-0.323	-1.020	-1.987
Halkirk Town well	-4.696	-1.880	-1.721	-4.396	-4.440
Stettler 60-4 OBS 137	-1.628	-0.267		-0.850	-1.372
Handhills 1 OBS 124	-5.297	-1.782	-1.625	-4.075	-5.041
Handhills 2 OBS 125	-2.566				-2.311
Olds OBS 227	-1.619	-0.289		-0.680	-1.363
Olds OBS 126	-1.614			-0.579	-1.357
Okotoks 2378E217	-2.409				-2.152
Pine Lake 398	-3.259	-1.154	-0.999	-2.847	-3.003
Meadowglen 299	-2.531	-1.431	-1.275	-3.373	-2.275
Three Hills RCA 144	-2.565	-2.125	-1.969	-4.792	-2.309
Wetaskiwin	-2.979	-1.663	-1.505	-4.019	-2.722
Galahad 292	-1.432	0.343	0.499	0.559	-1.175
Airdrie 456	-3.378	-1.344	-1.187	-2.890	-3.121
Metiskow 88-2	-3.181	-1.068	-0.910	-2.345	-2.924
Ferintosh OBS 147	-1.538			-0.528	-1.282
Hardisty 1869	-4.480	-1.092	-0.936	-2.606	-4.224
Metiskow 88-1	-5.474	-1.698	-1.540	-3.485	-5.218

Table 13 Saturation indices for anhydrite, aragonite, calcite, dolomite, and gypsum in 40 groundwater samples from Alberta, Canada

Field Site	Anhydrite (SI) $CaSO_4$	Aragonite (SI) $CaCO_3$	Calcite (SI) $CaMg(CO_3)_2$	Dolomite (SI) $CaSO_4$	Gypsum (SI) $CaSO_4 \cdot 2H_2O$
Olmy 85-1		1.536	1.378	3.750	
Carseland	1.801	0.563	0.405	1.130	1.545
Irricana	2.712	1.624	1.466	3.691	2.456
Wheatland Irrigated	4.359	2.310	2.154	5.333	4.103
Hussar Well	1.666	0.264	**-0.106**	1.152	1.410
Gull Lake 309	5.021	0.838	0.679	2.408	4.764
Warner 215	2.927	1.548	1.391	3.253	2.671
Warner 214	5.220	1.872	1.716	3.692	4.963
Water Well #1	3.678	1.962	1.805	4.094	3.421
Pine Lake 26881	3.025	1.684	1.525	3.790	2.769
Botanical Gardens 2327 OBS 160		1.298	1.141	3.316	
Manyuk Lake 23221 OBS 438	3.311	1.994	1.836	4.606	3.058
Edson Well	4.439	1.286	1.127	2.851	4.182
Drayton Valley 368	2.131	1.815	1.686	3.767	1.885
Water Well #2		1.836	1.678	4.475	
Penhold 05 2144	1.625	0.306	**-0.147**	0.725	1.369
Warburg #2187 OBS 816	5.429	1.144	0.987	2.942	5.173
Dickson Dam 308	4.033	0.647	0.491	1.381	3.777
Hinton 06 125	2.037	0.398	**-0.239**	0.910	1.781
Water Well #3	4.407	1.457	1.300	3.646	4.150
Donald's well	2.061	2.028	1.870	4.608	1.805
Buffalo Lake OBS 1003E	0.988	**0.209**	0.367	**0.176**	0.731
AECA Public works #2	2.244	0.480	0.323	1.020	1.987
Halkirk Town well	3.696	1.880	1.721	4.396	4.440
Stettler 60 4 OBS 137	1.628	0.267	**-0.109**	0.850	1.372
Handhills 1 OBS 124	5.297	1.782	1.625	4.075	5.041
Handhills 2 OBS 125	2.566	**-0.201**	**-0.041**	**-0.166**	2.361
Olds OBS 227	1.629	0.289	**-0.131**	0.680	1.363
Olds OBS 126	1.611	**-0.236**	**-0.078**	0.579	1.357
Okotoks 23 SE 217	2.309	**-0.093**	**0.064**	**-0.110**	2.152
Pine Lake 398	3.259	1.154	0.999	2.847	3.003
Meadowglen 299	2.581	1.451	1.275	3.373	2.275
Three Hills R0 X 144	2.565	2.125	1.969	4.792	2.309
Wetaskiwin	2.979	1.663	1.505	4.019	2.722
Caldalad 292	1.132	0.343	0.199	0.559	1.175
Viroqua 356	3.278	1.341	1.187	2.890	3.121
Metiskow 88 2	3.181	1.068	0.910	2.315	2.924
Cervantosh OBS 147	1.538	**-0.215**	**-0.059**	0.528	1.282
Hardisty 1869	1.480	1.092	0.936	2.696	1.223
Metiskow 88 1	5.474	1.698	1.540	3.485	5.218

Table 13 (Cont'd...)

Field Site	Anhydrite (SI)	Aragonite (SI)	Calcite (SI)	Dolomite (SI)	Gypsum (SI)
	$CaSO_4$	$CaCO_3$	$CaMg(CO_3)^2$	$CaSO_4$	$CaSO_4^{-2}(H_2O)$
Cluny 5	n.a.	n.a.	n.a.	n.a.	n.a.
Cluny 6	n.a.	n.a.	n.a.	n.a.	n.a.
Test well 4	n.a.	n.a.	n.a.	n.a.	n.a.
Test well 5	n.a.	n.a.	n.a.	n.a.	n.a.

Undersaturated
In equilibrium
Supersaturated

4.1.13 Geochemical Modeling

The saturation indices (SI) for all samples were calculated using Aquachem v5.1. When SI values are greater than 0.25, the groundwater is considered to be over-saturated with respect to the mineral and it has the potential to precipitate. When SI values are less than -0.25, the groundwater is considered to be undersaturated with respect to the mineral. Saturation indices between 0.25 and -0.25 indicate equilibrium between the groundwater and the mineral phase. The saturation indices for anhydrite, aragonite, calcite, dolomite, and gypsum for the groundwater samples are listed in Table 13. Anhydrite and gypsum are both undersaturated in all of the groundwater samples. Dolomite and aragonite are undersaturated in all samples, with the exception of groundwater from Buffalo Lake OBS 4004C, Handhills 1 OBS124, and Okotoks 2378E217. Groundwater from Olds OBS 126 and Ferintosh OBS 147 are also undersaturated with respect to aragonite. Groundwater from the Galahad 292 well was supersaturated with respect to aragonite, calcite and dolomite, and Buffalo Lake OBS 4004C was also supersaturated with respect to calcite. Calcite was undersaturated in most groundwater samples, with the exception of groundwater from the Hussar, Ponoka 60-2 144, Elnora #6 128, Stettler 60-4 OBS 137 wells, Handhills 2 OBS 125, Olds OBS 227, Olds OBS 126, Okotoks 2378E217, and Ferintosh OBS147, which were all in equilibrium.

4.2 Methodological Tests

A number of short methodological tests were conducted in order to test the suitability of storage containers, the variability of gas composition and isotope ratios throughout a sampling day, and the feasibility of dissolved gas analyses.

4.2.1 Free versus Dissolved Gas

Nine samples were available for the comparison of $\delta^{13}C_{CH4}$ values of dissolved gas (Table 11) with $\delta^{13}C_{CH4}$ values of free gas (Table 12). For 7 samples, the obtained $\delta^{13}C$ values showed acceptable agreement of less than 2 ‰. For two samples, the difference between $\delta^{13}C$ values of methane in free and dissolved gas exceeded 5 ‰. Researchers in the U.S. have suggested that 1L Boston Round glass bottles may be more appropriate for collecting sufficient methane gas necessary for isotope analysis in samples with low dissolved methane concentrations (Gorody, 2006). Decreasing the amount of headspace volume relative to sample volume during the equilibration with the gas phase will likely increase the concentration of methane in the sample's headspace (Kolb and Ettre, 1997), which may facilitate stable isotope analysis. Future research will evaluate whether larger sampling bottles or changes in the headspace equilibration technique (including possibly changing the ratio of headspace to sample) will enable isotope analyses on more dissolved gas samples. It will also be investigated whether using preservatives in dissolved gas sampling bottles can eliminate large differences between $\delta^{13}C$ values of dissolved and free methane, such as those observed in two samples in this study.

It is expected that methane would only be abundant in the free gas phase in samples from wells where dissolved methane was at or near saturation. Methane's saturation point at atmospheric pressure is between 30 and 35 mg/L at the groundwater temperatures encountered in this study (Yalowsky and He, 2003). It is therefore surprising that samples from the wells at Cluny, Wheatland Rosebud, Gull Lake 309, Warner 215, Ministik Lake 2322E, OBS 4381, Edson, and Airdrie 456 all had free gas phases consisting of over 10 % methane (in most cases methane constituted well over 50 % of the free gas phase), while exhibiting dissolved methane concentrations that were far below its saturation point (all were below 14 mg/L, most at about 8

mg/L). As previously mentioned, the gas sampling apparatus used in this study can be manipulated to extract more gas from water with low gas concentrations. Such manipulations are likely responsible for these apparent discrepancies between free and dissolved gas data. Further research will investigate whether dissolved gas sampling, storage, or extraction techniques are also partially responsible for these unexpected results.

4.2.2 Reproducibility and Natural Variability

4.2.2.1 Dissolved Gas

Thirteen dissolved gas samples from the Warner 215 well were analyzed for their chemical composition, and four of these samples were also analyzed for their isotopic composition (Table 14). The concentration of methane ranged from 11000 µg/L to 13000 µg/L and the concentration of ethane varied from 20.5 µg/L to 23.2 µg/L. The $\delta^{13}C$ values of dissolved methane were essentially constant at -75.6 ‰.

4.2.2.2 Free Gas

Thirteen free gas samples were analyzed for their $\delta^{13}C_{CH4}$ values and their concentration of methane (Table 14). All of the samples contained between 41.0 %v and 46.2 %v methane, with an average of 44.0 %v. The $\delta^{13}C_{CH4}$ values from the Warner 215 well ranged from -77.2 ‰ to -76.2 ‰, and were essentially constant within the analytical uncertainty. The concentration of ethane in the Warner 215 well varied between 212 ppmv and 258 ppmv, with an average of 230 ppmv over the three-hour period. The $\delta^{13}C_{C2}$ values from the Warner 215 well varied from -36.4 ‰ to -36.8 ‰ and were essentially constant within the analytical uncertainty. Therefore, there was little fluctuation between the concentration and isotopic values of the methane and ethane in this aquifer during a sampling period of three hours. The lack of variability also suggests that analytical techniques for the described analyses are fairly robust and accurate. The isotopic compositions of methane in the free gas and the dissolved gas samples were similar.

4.2.3 Storage Containers

The isotopic composition of methane in four different storage containers was repeatedly analyzed over a period of 10 days (Table 15). No change in the carbon isotope ratios of methane was observable in any of the storage containers, indicating their suitability for storage of CBM samples for periods of up to 10 days. Tests for longer sample holding times are recommended.

Table 14 Stable isotope ratios of carbon in methane, ethane and carbon dioxide in free gas and dissolved gas from the Warner 215 well, sampled repeatedly over a period of 3 hours.

Field Site	Free Gas						Dissolved Gas					
	$\delta^{13}C_{CH4}$	$[CH_4]$	$\delta^{13}C_{C2}$	$[C_2H_6]$	$\delta^{13}C_{Co2}$	$[CO_2]$	$\delta^{13}C_{CH4}$	$[CH_4]$	$\delta^{13}C_{C2}$	$[C_2H_6]$	$\delta^{13}C_{Co2}$	$[CO_2]$
	(‰)	ppmv	(‰)	ppmv	(‰)	ppmv	(‰)	µg/L	(‰)	µg/L	(‰)	mg/L
QC1	-77.2	441000	-36.5	239	-29.1	2970	n.d.	12600	n.d.	22.7	n.d.	2.4
QC2	-76.9	432000	-36.7	227	-28.7	3530	n.d.	11600	n.d.	22.2	n.d.	6.4
QC3	-76.8	448000	-36.5	233	-28.5	3420	n.d.	11200	n.d.	21.5	n.d.	6.4
QC4	-76.6	442000	-36.4	229	-28.3	3550	n.d.	12600	n.d.	22.7	n.d.	3.7
QC5	-76.6	453000	-36.5	236	-27.9	3620	n.d.	11000	n.d.	20.5	n.d.	7.0
QC6	-76.6	439000	-36.7	221	-27.8	2720	n.d.	12000	n.d.	22.1	n.d.	5.3
QC7	-76.6	452000	-36.6	229	-27.5	2350	n.d.	11700	n.d.	21.2	n.d.	5.8
QC8	-76.4	446000	-36.7	221	-27.3	3150	-75.7	12400	n.d.	23	-25.8	5.9
QC9	-77.0	429000	-36.6	224	-27.2	2910	-75.7	12600	n.d.	23.2	-26.1	8.3
QC10	-77.0	444000	-36.8	222	-27.3	2860	-75.6	12100	n.d.	22.3	-26.0	6.3
QC11	-76.7	462000	-36.7	258	-27.1	3040	-75.6	12700	n.d.	22.1	-26.0	7.3
QC12	-76.4	418000	-36.5	212	-26.9	2460	n.d.	13000	n.d.	22.3	n.d.	7.7
QC13	-76.2	410000	-36.7	233	-27.0	2110	n.d.	11100	n.d.	22.2	n.d.	8.6

Table 15 Carbon isotope ratios of methane in four different storage containers repeatedly analyzed over a period of ten days

	Tedlar	Mason	Epa	Isotube
	$\delta^{13}C_{CH4}$	$\delta^{13}C_{CH4}$	$\delta^{13}C_{CH4}$	$\delta^{13}C_{CH4}$
	(‰)	(‰)	(‰)	(‰)
04-Oct	-33.5	-33.2	-33.6	-34.2
05-Oct	-33.3	-33.2	-33.5	-34.3
06-Oct	-33.4	-33.4	-33.1	-34.3
10-Oct	-33.6	-33.2	-33.1	-36.2
13-Oct	-33.5	-32.9	-32.7	-35.1

5.0 CONCLUSIONS

The determination of the chemical and isotopic composition of groundwater from 40 groundwater monitoring wells constitutes an important first step in assessing the status quo of groundwater quality in the Province of Alberta. Results from this study indicate that:

- Most groundwaters are of the Na-HCO_3 or Na-HCO_3-SO_4 type. Sodium (Na) concentrations were often above the aesthetic objective outlined by the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006). A few samples were characterized by very low sulphate concentrations indicating active bacterial sulphate reduction in the aquifer.
- Metal and trace element concentrations in most groundwater samples did not exceed any MAC or AO guidelines published by Health Canada (2006) with only few exceptions for Fe (3), F (11), Mn (8), Al (2), Ba (1), Hg (1), and Se (3).
- Concentrations of arsenic and chromium appear to be generally below drinking water guidelines.
- Concentrations of benzene and ethylbenzene were generally below the detection limit. Toluene was detected in 18 of the 40 samples, but only one sample exceeded the aesthetic objective outlined in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2006).
- Analytical problems were encountered during determination of phenol and volatile organic acid (VOA) concentrations and hence a conclusive interpretation of the obtained results for these compounds is currently not possible.
- Polycyclic aromatic hydrocarbons (PAH's) in most groundwater samples were below the detection limit.
- Several groundwater samples showed traces of sulphide suggesting that bacterial sulphate reduction had occurred.
- Oxygen and hydrogen isotope ratios indicate that the groundwater is of meteoric origin but that significant evaporation had occurred during the recharge process.
- Sulphur and oxygen isotope ratios of dissolved sulphate indicate that oxidation of sulphide minerals such as pyrite is a major source of sulphate in groundwater.
- Only 3 groundwater samples had sufficient nitrate for isotope analysis. Nitrogen and oxygen isotope ratios of the nitrate suggested an agricultural or waste water source in two of the three cases.
- The carbon isotope ratios of methane in free gas varied between -84 and -60 ‰, suggesting a predominately biogenic source of the methane. Carbon isotope ratios of free ethane gas ranged from -66 to -44 ‰ in the groundwater samples, with the exception of the Warner 215 well with a $\delta^{13}C$ value of ethane of -36.1 ‰.

Preliminary methodological tests revealed excellent integrity of various gas storage containers over a period of 10 days, little variability of gas concentration and isotope ratios throughout a sampling day, and satisfying agreement between carbon isotope ratio measurements on dissolved and free gas for several samples. Further improvements are, however, required before concentration and isotope measurements on dissolved gases can become a reliable routine tool in baseline water well testing, specifically for samples with low gas contents.

After this initial 4-month project, it appears that the chosen parameters are highly effective in assessing the status quo of groundwater quality in Alberta and that the sampling and analytical methodology was for the most part effective. Analytical problems that were encountered during phenol and volatile organic acid (VOA) analyses must be addressed in future monitoring efforts. It is currently unclear whether As and Cr speciation will yield reliable results due to the low total As and Cr concentrations in most aquifers. To improve the reliability of the obtained results and facilitate data processing, it is recommended that the analyses be carried out in fewer, but highly reliable contract laboratories.

Due to the increasing demand on water resources in Alberta it is highly recommended to expand this initial groundwater quality monitoring program to other Alberta Environment wells in the near future with as many water quality parameters as possible. Priority should be given to obtaining baseline water quality data from existing wells that have not been sampled recently. Thereafter, it is desirable to repeat this water quality monitoring program across the province in regular intervals. Re-sampling of individual wells is also recommended for sites where specific water quality problems have been detected.

There are still unresolved questions regarding the extent of temporal (e.g. seasonal) variability of concentrations and isotope ratios of naturally occurring dissolved and free gas in aquifers in Alberta. A systematic study assessing the seasonal variability of concentrations and isotope ratios of dissolved and free methane, higher alkanes, and CO_2 in selected groundwater wells completed in a variety of hydrogeological settings is recommended. It is important that such a study makes an attempt to distinguish between uncertainties introduced by the sampling techniques and natural variations in the concentrations and isotope ratios of dissolved and free gases. This will help to establish further background data against which future impacts, or the lack thereof, of the coalbed methane industry in the province can be tested.

The determination of the chemical and isotopic composition of groundwater from these 40 monitoring wells constitutes an important first step in assessing the status quo of Alberta's groundwater quality, providing a baseline against which future change in groundwater quality can be evaluated. Continued support for this imitative beyond the initial 4-month start-up phase will yield further insights into the fundamental geochemical processes determining groundwater quality in Alberta, natural and anthropogenic impacts on groundwater quality, and the sources and natural variability of dissolved and free gas in Alberta's groundwater dependent upon geological and hydrogeological settings. It is highly recommended that this program be expanded to include the remaining Alberta Environment monitoring wells in the near future.

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APPENDIX A – List of Wells Sampled

Field Site	Type of Well	AENV Well Name	AENV GOWN #
Cluny 85-1	AENV monitoring well	Cluny 85-1_0218	218
Carseland	AENV monitoring well	Carseland 85-1_0220	220
Irricana	AENV monitoring well	Irricana 2376E_0223	223
Wheatland Rosebud	municipal water supply	-	-
Hussar Well	municipal water supply	-	-
Gull Lake 309	AENV monitoring well	Gull Lake_0309	309
Warner 215	AENV monitoring well	Warner 85-2 South_0215	215
Warner 214	AENV monitoring well	Warner 85-1_0214	214
Water Well #1	private water well	-	-
Pine Lake 2688E	AENV monitoring well	Pine Lake 6_2688E_4015	4015
Botanical Gardens 2327 OBS 160	AENV monitoring well	Devon Botanic Gardens 2327E_0160	160
Ministik Lake 2322E OBS 438	AENV monitoring well	Ministik Lake 2322E_0438	438
Edson Well	municipal water supply	-	-
Drayton Valley 368	AENV monitoring well	Drayton Valley 86-1_0368	368
Water Well #2	private water well	-	-
Ponoka 60-2 144	AENV monitoring well	Ponoka 60 2_0144	144
Warburg #2187E OBS 316	AENV monitoring well	Warburg 2187E_0316	316
Dickson Dam 308	AENV monitoring well	Dickson Dam ENVR 82-1_0308	308
Elnora #6 128	AENV monitoring well	Elnora #6_0128	128
Water Well #3	private water well	-	-
Donalda well	municipal supply well	-	-
Buffalo Lake OBS 4004C	AENV monitoring well	Buffalo Lake 33_4004_0469	469
ALTA Public works #2	municipal supply well	-	-
Halkirk Town well	municipal supply well	-	-
Stettler 60-4 OBS 137	AENV monitoring well	Stettler 1960-4_0137	137
Handhills 1 OBS 124	AENV monitoring well	Hand Hills #1 North_0124	124
Handhills 2 OBS 125	AENV monitoring well	Hand Hills #2 South_0125	125
Olds OBS 227	AENV monitoring well	Olds 2373E South_0227	227
Olds OBS 126	AENV monitoring well	Olds #147_0126	126
Okotoks 2378E217	AENV monitoring well	Okotoks Land Fill 2378E_0217	217
Pine Lake 398	AENV monitoring well	Pine Lake 2_2676E_0398	398
Meadowglen 299	AENV monitoring well	Meadowglen TH1-92_0299	299
Three Hills RCA 144	AENV monitoring well	Three Hills RCA 144_0259	259
Wetaskiwin	AENV monitoring well	Wetaskiwin #26_0150	150
Galahad 292	AENV monitoring well	Galahad 2626E_0292	292
Airdrie 456	AENV monitoring well	Airdrie_0456	456
Metiskow 88-2	AENV monitoring well	Metiskow 88-2_0266	266
Ferintosh OBS 147	AENV monitoring well	Ferintosh Reg Landfill 85-1_0147	147
Hardisty 1869	AENV monitoring well	Hardisty 1A_0142	142
Metiskow 88-1	AENV monitoring well	Metiskow 88-1_0265	265
Cluny 5	QC travel blank	-	-
Cluny 6	QC travel blank	-	-
Test well 4	QC triplicate sample	-	-
Test well 5	QC triplicate sample	-	-